AFRL-SN-WP-TR-2000-1085

ELECTRONIC WARFARE (EW) RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval2)

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A UNIT OF MERCER UNIVERSITY
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JULY 2000

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THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

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13. ABSTRACT *(Maximum 200 words)*
EW Receiver and Processing Concepts Evaluation Program (RAPCEval 2) tasks have provided analytical support for current research for the Electronic Signal Measurement (ESM) group at Air Force Research Laboratory. Tasks initiated under OPTION 3 of the contract of this program provided analysis for inputs and countermeasures for electronic receivers of radar, electro-optic, infrared, and ultraviolet systems. Research has been performed under the direction of the Joint Program Research Standards Committee, composed of members from Wright-Patterson AFB, Warner Robins AFB, Mercer University, and Mercer Engineering Research Center. The report includes research presentations and reports from graduate students. Topics included are represented in the keyword list of this form.

14. SUBJECT TERMS
RAPCEval, Reed-Solomon codes, imaging, parallel processing, RAD, signal processing

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

This report describes work accomplished under contract Option 1 of the Electronic Warfare (EW) Receiver and Processing Concepts Evaluation Program (RAPCEval 2). The Air Force Research Laboratory (AFRL) awarded this contract. This branch of AFRL is located at Wright-Patterson Air Force Base (W-PAFB), Ohio. The Option 1 task of this program was awarded to Mercer Engineering Research Center (MERC) on October 15, 1997. Work was completed on the RAPCEval 1 contract in October 1996, and this contract was initiated in November 1996. This report describes work accomplished on the contract from April 1, 1999 through March 30, 2000. The project includes 5 options and has maximum duration of 60 months from the date of award. In support of the contract, a number of activities and projects have been initiated. Some of these are complete, and many more are continuing. A number of activities have spawned new directions for investigative effort.

The Program Research Standards Committee (PRSComm), established at the outset of the Basic task, has continued to meet regularly and has provided valuable guidance and suggestions both as to the direction of students involved in the effort, and the scope and emphasis of the research efforts in general. Current membership of this committee represents the Air Force Research Laboratory, Robins Air Force Base, Mercer University, and Mercer Engineering Research Center. The specific members are listed in another section of this report (Section 4, Research Support).

Four meetings of the PRSComm were held during contract Option 2. A number of student research reviews were presented and were approved by the PRSComm in the course of these meetings (see Section 5, Project Activity). Valuable discussion and suggestions were provided for directing and focusing the students' work. In addition, several committee members suggested ways to reduce the scope or better focus research efforts. Frequently, unanticipated or unknown resources and techniques were pointed out for the benefit of the students. One meeting involved a presentation by AFRL researcher James Stephens, who delivered a visiting lecture with an emphasis on communication countermeasures, with focus on advanced digital signal processing for electronic warfare.

Students engaged in the RAPCEval program have continually enjoyed fruitful contact with knowledgeable personnel at the AFRL in their respective areas of interest. They have also interacted with experienced colleagues at Robins Air Force Base, employees of MERC, Mercer University School of Engineering faculty, and various representatives of industry.

It should be noted that software generated under this contract is not government-owned.

The RAPCEval contract has stimulated gratifying communication and collaborative research effort among students, university faculty, MERC personnel, and personnel at the AFRL, Warner Robins AFB and industry. All parties have expressed satisfaction with the contract results.

2. INTRODUCTION

These tasks specify requirements for analytical and research support of in-house research at the AFRL, Air Force Research Laboratory/Sensors Division (AFRL/SNR). There is increasing sophistication, quantity, and mobility of hostile radars, such as anti-aircraft missile (AAM), surface-to-air missile (SAM), and anti-aircraft artillery (AAA) fire control systems. Electronic warfare receivers for radar, electro-optic, infrared, ultraviolet missile warning and electronic countermeasures need operational upgrades to allow penetrating aircraft acceptable survivability. This encourages maintenance of in-house laboratories to support development, to evaluate concepts, and to test new receivers, processors, and software.

2.1 EW Receiver Effort

Complex EW environments have caused employment of numerous receiving systems. Augmentation of in-house capability for evaluation, novel concept development, and exploitation of new technology is needed. Computer-aided simulation of new systems and concepts can save resources. New high speed analog-to-digital (A/D) converter technology may allow input frequencies to be digitized in base-band before the crystal video detector, possibly allowing real time digitized frequency, pulse width, and pulse amplitude. Advancing materials technology for infrared (IR) / ultraviolet (UV) / radio frequency (RF) energy offers the possibility of augmented and combined sensors. Investigation of these materials is needed to reduce the kind and number of avionics needed in combat. Filtering and discrimination advances in hardware and software may allow enhancement of fielded EW systems.

2.2 EW Processing Effort

A modern EW system must face an increasing number of hostile threats that are multimode. Sensors to intercept such threats now include radar warning and electronic intelligence systems. Information from these sensors must be processed, the threat identified, and appropriate countermeasures initiated to counter these threats. An augmentation of in-house capability is required to evaluate processor hardware and software, to exploit novel ideas, and to investigate advanced concepts such as artificial intelligence to determine the nature of the threat, and what countermeasures, if any, to employ.

2.3 EW Exciter Effort

Digital exciters are being developed to provide a flexible active electronic countermeasures (ECM) asset against a wide variety of modern threats. The need exists to evaluate the various exciter architectures, advance and develop unique concepts, and advance the digital exciter technology base. The novel concepts and technologies must be evaluated for effectiveness against the proposed application.

2.4 EW Antenna Effort

The role of antennas as the "eyes and ears" of the sensor suites continues to make RF antenna technology development vital to the Air Force mission. Airborne antenna apertures of the future will be low cost, broadband, low radar cross section (RCS), and multifunction in nature to earn their way onto platforms where space is at a premium.

3. SCOPE

The overall program consists of a basic task and four options that are the conglomerate of different work efforts and technologies within the EW arena. Detailed descriptions are given as follows:

- Basic Task - The basic task will provide the tasks necessary to analyze software and hardware approaches to perform the exploratory development of EW technology in these technology areas: radar hardware, laser hardware, infrared hardware, and ultraviolet hardware. The task will analyze receiver and exciter technology to generate ECM signals to improve ECM system performance. In addition, the scope of the basic task will include signal processing technology related to the hardware.

- Option 1 - These tasks will be those necessary to analyze receiver technology for application to modern digital spectrum estimation techniques in order to improve EW / signal intelligence (SIGINT) / electronic intelligence (ELINT) / IR / electro-optical (EO) receiver performance.

- Option 2 - This option consists of those tasks necessary to identify high risk design areas for an EW / SIGINT / ELINT / IR / EO hardware approach, to perform exploratory design assessments for selected functions, and to determine the degree of parallel processing achievable.

- Option 3 – This option is "reserved."

- Option 4 - These tasks are those essential to EW / SIGINT / ELINT / IR / EO hardware and signal processing including, but not limited to, pulse-deinterleaving, parametric extraction, and threat identification.

4. RESEARCH SUPPORT

For support of the overall contract, a "PRSComm" has been established. Membership for this committee was most recently updated March 1997. Current members are:

- from the Air Force Research Laboratory at W-PAFB,
  - Mr. Nicholas Pequignot (the program manager for AFRL)
  - Mr. Emil R. Martinsek
  - Mr. Norman A. Toto
  - Dr. Duane A. Warner
  - Mr. Paul J. Westcott

- from Warner Robins Air Logistics Center (WR-ALC),
  - Mr. Steve Strawn (the program manager for WR-ALC)
  - Mr. John LaVecchia
  - Mr. Phil Oliver
  - Mr. Ches Rehburg
  - Mr. Larry Sheets

- from Mercer University and MERC,
  - Dr. Tom Bass (the program manager for MERC)
  - Dr. David Barwick, (chairman of the standards committee)
  - Dr. Aaron Collins (Mercer University)
  - Dr. Behnam Kamali (Mercer University)
  - Dr. Paul MacNeil (Mercer University)

The EW Receiver and Processing Concepts Evaluation Program was awarded to MERC by Wright-Patterson Air Force Base/AFRL under contract F09603-93-G-0012-0017. This contract is administered through WR-ALC. The overall program has a funding ceiling of $499,940. Incremental funding will be accomplished via a series of contract options. The basic contract is $99,998, Option 1 is $99,998, Option 2 is $99,998, Option 3 is “reserved”, and Option 4 is $49,998.

Funds have been provided for the basic program, Option 1, Option 2, and Option 4.

5. PROJECT ACTIVITY

5.1 Steering Committee, May 1999

5.1.1 Meeting Minutes

RF/Receiver and Processing Concepts Evaluation Program Program Research Standards Committee Meeting Minutes 12 May 1999

A meeting of the PRSComm for the RAPCEval program was hosted by Mercer University at 1:45 p.m. Committee members present were Tom Bass, Dave Barwick, Aaron Collins, Behnam Kamali, Paul MacNeil, Phil Oliver, Nick Pequignot, Ches Rehberg, and Steve Strawn. Also present were several representatives from Mercer University, students scheduled to speak, and representatives from the AFRL. All of the presentations were reports on research in progress.

After welcoming remarks by Dr. Barwick, Dr. Tom Bass gave a brief description of the RAPCEval program, including an overview of some of the projects completed by students, and introduced the students who were scheduled to speak; Kerwin Holmes, Mark Napier, and Steve Boswell.

Kerwin Holmes described his efforts to date to apply error control coding to Global Positioning Satellite (GPS) development. The work is motivated in part by the fact that a GPS upgrade has been initiated. New location error tolerances in the range of less than 10 meters will be required. Techniques such as convolution, interleaving, and turbo codes, as well as the Reed/Solomon coding technique are under consideration. Questions from the attendees addressed the issue of sharpening the goals and boundaries of this work.

At approximately 2:15 p.m. Mark Napier reviewed his work on the application of a Reed/Solomon encoding scheme to improve a proposed collision avoidance system. The proposed scheme is to use current transponder technology to transmit at random intervals GPS position and velocity along with barometric altitude in addition to the existing mode S messages used for identification. A particular Reed-Solomon code has been selected to match the available message length, and design of a suitable decoder is under way.

The third speaker, Stephen Boswell, described his work on the application of a neural net to the recognition problem for an Air Force Infrared Missile Warning System (AN/AAR-47). He described the process of training the neural net in regard to the problem of interest by the use of samples derived from both true and false targets. While the results to date are inconclusive, some valuable opportunity to redirect effort became apparent as his talk proceeded. All agreed that this effort could prove valuable to the problem of false alarm that has been experienced with the use of this equipment.

During the steering committee discussion, following the presentations by students, a number of comments were forthcoming in regard to the student efforts. Nick Pequignot suggested that Mark Napier undertake a Defense Technical Information Center (DTIC) search in view of the fact that Interrogate Friend or Foe (IFF) efforts are funded by the Navy. Mr. Pequignot also proposed that a new Basic Order Agreement (BOA) be executed in order to continue the RAPCEval program. The meeting was then adjourned.

5.1.2 Meeting Agenda

Agenda

RAPCEval program

STEERING COMMITTEE MEETING

99 May 12 — 1:30 PM to 4:15 PM
Conference Room, Mercer Engineering Research Center
135 Osigian Boulevard, Warner Robins, GA

Meeting called by: Nicholas Pequignot, AFRL/SNRP, Air Force Research Laboratory Program Manager

Facilitator: Dr. Tom Bass

	AF Research Laboratory	Robins AFB	Mercer University
Committee Members:	Mr Nicholas A Pequignot	Mr Steve Strawn	Dr David Barwick
	Mr Emil R Martinsek	Mr John LaVecchia	Dr Tom Bass
	Mr Norman A Toto	Mr Phil Oliver	Dr Aaron Collins
	Dr Duane A Warner	Mr Ches Rehberg	Dr Behnam Kamali
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	westcopj@sensors.wpafb.af.mil	sheets@ewir-wr.robins.af.mil	kamali_b@mercer.peachnet.edu

Schedule - revised		
Greetings	Dr David Barwick	1:30 PM – 1:35 PM
Meeting Overview	Dr Tom Bass	1:35 PM - 1:45 PM
Student Proposals		
Application of Error Control Coding for GPS Development	Mr. Kerwin Holmes	1:45 PM – 2:15: PM
Civil IFF Reed-Solomon Code Application	Mr. Mark Napier	2:15 PM – 2:45: PM
Novel Approaches to Evaluation of UV Receiver Data	Mr. Steve Boswell	2:45 PM – 3:15 PM
Discussions & New Business	Dr. Tom Bass	3:15 PM - 3:45 PM
Adjourn		4:15 PM

5.1.3 Attendance Roster

The attendees at this meeting are listed here:

ATTENDANCE REGISTER -
RAPCEval Meeting 5/12/99

#	First Name	Last Name	Company	Business Phone	E-mail Address
1	Tom	Bass	MERC	(912) 953-6800	bass_wt@mercer.edu
2	Duane	Warner	AFRL/SNJW	(937) 255-4174 x4003	warnerda@sensors.wpaft.af.mil
3	Robert	Parks	AFRL/SNRW	(937) 255-5579 x4248	parksrs@sensors.wpafb.af.mil
4	Charles	Bass	MERC	(912) 953-6800	cbass@merc.mercer.edu
5	Behnam	Kamali	Mercer University School of Eng.	(912) 752-2415	kamali_b@mercer.edu
6	Phil	Oliver	WR-ALC/LN	(912) 926-2588	oliver@ec.robins.af.mil
7	Steve	Strawn	WR-ALC/LNERR	(912) 926-6435	steve.strawn@robins.af.mil
8	Nick	Pequignot	AFRL/SNRP	(937) 255-6127 x4235	nicholas.pequignot@sn.afrl.af.mil
9	Paul E.	MacNeil	Mercer University School of Eng.	(912) 752-2185	macneil_pe@mercer.edu
10	Mark	Napier	Scientific Atlanta - Sugarloaf Ofc	(770) 236-6980	mark.napier@sciatl.com
11	Ches	Rehberg	WR-ALC/LNEX	(912) 926-4525	ches.rehberg@robins.af.mil
12	Aaron	Collins	Mercer University School of Eng.	(912) 752-2097	collins_as@mercer.edu
13	Kerwin	Holmes	WR-ALC/LYSKS (Jstars)	(912) 327-2880	holmeskr@robins.af.mil
14	Stephen	Boswell	ARINC	(912) 926-0483	boswell@fiamg.net
15	David	Barwick	MERC	(912) 953-6800	dbarwick@merc.mercer.edu

5.1.4 Overview of the Program (Dr. Bass)

The overview briefing of the RAPCEval Program as presented at this meeting is reproduced on the next nine pages.

EW RECEIVER AND PROCESSING CONCEPTS
EVALUATION PROGRAM
(RAPCEval) OVERVIEW

May
1999

RAPCEval STEERING COMMITTEE MEETING

May 12, 1999

EW RECEIVER AND PROCESSING CONCEPTS
EVALUATION PROGRAM
(RAPCEval) OVERVIEW

May
1999

GENERAL PROGRAM INFORMATION

- ★ Contract: F09603-93-G-0012-0017
- ★ Customer: Air Force Research Laboratory, Sensors Division (AFRL/SN)
- ★ Contract Value: $349,964

PROGRAM STATUS

- ★ Graduate Research Jointly Supported by Mercer, AFRL, WR-ALC, and Industry
- ★ Twelve successful research projects (with Masters' degrees) have been completed
- ★ Five ongoing research projects
- ★ Research has been approved by the steering committee to be useful to the Air Force
- ★ Research has been found to have academic merit by by the university and by the committee

EW RECEIVER AND PROCESSING CONCEPTS
EVALUATION PROGRAM
(RAPCEval) OVERVIEW

May 1999

PROGRAM RESEARCH STANDARDS COMMITTEE MEMBERS

- ★ AF RESEARCH LAB
  - Mr. Nick Pequignot (PM)
  - Mr. Emil R. Martinsek
  - Mr. Norman A. Toto
  - Dr. Duane A. Warner
  - Mr. Paul J. Westcott
- ★ MERCER UNIVERSITY
  - Dr. Aaron Collins
  - Dr. Benham Kamali
  - Dr. Paul MacNeil
- ★ WR-ALC
  - Mr. Steve Strawn (PM)
  - Mr. John LaVecchia
  - Mr. Phil Oliver
  - Mr. Ches Rehburg
  - Mr. Larry Sheets
- ★ MERC
  - Dr. Dave Barwick (Chmn)
  - Dr. Tom Bass (PM)

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

May 1999

GRADUATES

- ★ *Mark Astin,* "Application of Parallel Computing Techniques to the RAD Algorithm", AFRL-SN-WP-TR-1998-1088 (classified)
- ★ *Henderson Benjamin,* "Selection of Reed Solomon Codes Using Neural Networks" (unclassified) AFRL-SN-WP-TR-1998-1056, p. 131
- ★ *Ron Brinkley,* "Burst Error Correction with Reed-Solomon Codes" to be included in forthcoming RAPCEval annual report (unclassified)

GRADUATES

- ★ *Mark Campbell,* "Auto-Regressive Spectral Analysis - EW Applications", unclassified report, available from MERC
- ★ *Randy Ford,* "Passive Location via Evolutionary Genetic Algorithms", to be included in forthcoming RAPCEval annual report (unclassified)
- ★ *Claus Franzkowiak,* "Four-Pulse Primary RAD Filter Development", AFRL-SN-WP-TR-1998-1087

GRADUATES

- ★ *Neal Garner*, "Error Correction and Prediction for Improved Communication of Time and Time Measurements", unclassified report, available from MERC
- ★ *Joseph Kelley* , "A Parameter Determination Alternative for RAD Analysis", WL-TR-95-1005 (classified).
- ★ *Joseph Kelley*, "MultiGroup Simultaneous RAD Parameter Selection", WL-TR-97-1094 (classified).

EW RECEIVER AND PROCESSING CONCEPTS
EVALUATION PROGRAM
(RAPCEval) OVERVIEW

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1999

GRADUATES

★ *Max Roesel,* "Agile RF/PRI Radar Analysis via RAD", WL-TR-95-1020 (classified)

★ *Dave Schuler,* "Comparison of Algorithms for Geolocation of Radar Signals", available from MERC (with need to know)

★ *Tracy Tillman,* "Hardware Implementation for an Advanced Pulse Processing Algorithm", edits in process at MERC

★ *Kirk Wright,* "Object Oriented Modeling of the AN/ALQ-172" AFRL-SN-WP-TR-1998-1086 (classified)

EW RECEIVER AND PROCESSING CONCEPTS
EVALUATION PROGRAM
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May 1999

TODAY'S STUDENT PRESENTATIONS

- ★ *Mark Napier,* "Application of Reed-Solomon Codes to Improve Noise Resistance of Civil IFF Communication"
- ★ *Kerwin Holmes,* "Application of Error Control Coding for GPS Development"
- ★ *Steve Boswell,* "Application of Neural Net with Fuzzy Logic Control to AN/AAR-47 Data"

5.1.5 Presentation by Steve Boswell

The student briefing presented by Steve Boswell at this meeting is reproduced on the next 24 pages.

ELECTRONIC WARFARE CONCEPTS
EVALUATION PROGRAM
(RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PRESENTATION

S. Boswell
ARINC, Inc./WR-ALC
Principal Analyst

Research Topic:

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM
(RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

PROBLEM STATEMENT

To acquire AN/AAR-47 data and apply DSP techniques to the data. Then present the data to a Neural Network with a Fuzzy Logic Controller which speeds learning. The Neural Network will learn the difference between threats and false alarms.

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

PROPOSAL JUSTIFICATION

★ Applicability to Mercer University MSSS Program
- Applying AI and DSP techniques to a problem

★ Applicability to the USAF
- Determine if techniques will improve reliability of AN/AAR-47 to accurately determine targets

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM
(RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH OBJECTIVES

★ Build/Acquire Neural Network
- Basic Back-Propagation Network
- Implement Fuzzy Logic Controller in NN
- Verify NN using standard XOR problem

★ Acquire/Analyze Data
- Observe Data peculiarities visually
- Pass data through various DSP techniques
- Train NN with DSP variables

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

METHOD OF INVESTIGATION

★ AN/AAR-47 Data Analysis
- Apply FFT to raw data
- Apply FFT to detrended data
- Apply Wavelet Transform to data
- Perform power analysis data
- Perform autocorrelation technique to data
- Place data into NN and try to train

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

Schedule/Actual

- ★ Semester 1
  - Build NN
  - Add FLC to NN
  - Acquire data and perform preliminary analysis
- ★ Semester 2
  - Determine useful parameters that describe data
  - Train NN to differentiate between threats and false alarms

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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

- ★ NN was programmed and tested with XOR problem
  - 505 Epochs were needed to train data
- ★ FLC was added to NN and tested with XOR problem
  - FLC controlled NN was much faster to train
  - 19 Epochs were needed to train data
- ★ Data from AN/AAR-47 was acquired
  - Data has been analyzed and has not been successfully trained

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MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

Fuzzy Associative Memory (FAM) for Learning Rate

CCE \ CE	NB	NS	ZE	PS	PB
NB	NS	NS	NS	NS	NS
NS	NS	ZE	PS	ZE	NS
ZE	ZE	PS	PS	PS	ZE
PS	NS	ZE	PS	ZE	NS
PB	NS	NS	NS	NS	NS

NB - Negative Big
NS - Negative Small
ZE - Zero
PS - Positive Small
PB - Positive Big
CE - Change of Error
CCE - Change of CE

RESEARCH PROGRESS

Fuzzy Associative Memory for Momentum

CCE \ CE	NB	NS	ZE	PS	PB
NB	NS	NS	ZE	ZE	ZE
NS	NS	ZE	ZE	ZE	ZE
ZE	ZE	PS	PS	PS	ZE
PS	ZE	ZE	ZE	ZE	NS
PB	ZE	ZE	ZE	NS	NS

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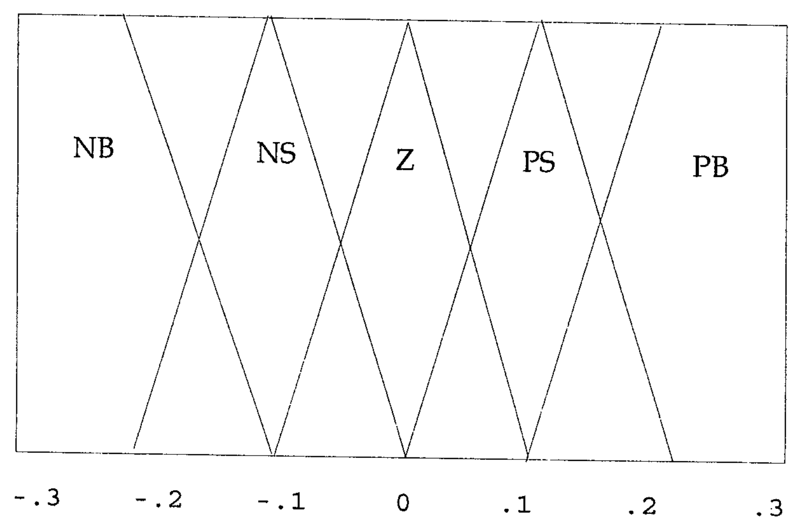
RESEARCH

RESEARCH PROGRESS

Input Variables CE and CCE



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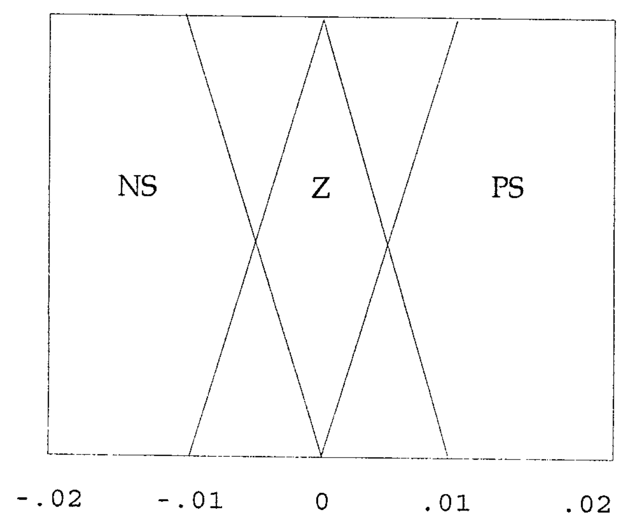
RESEARCH

RESEARCH PROGRESS

Output Variables Momentum and Learning Rate



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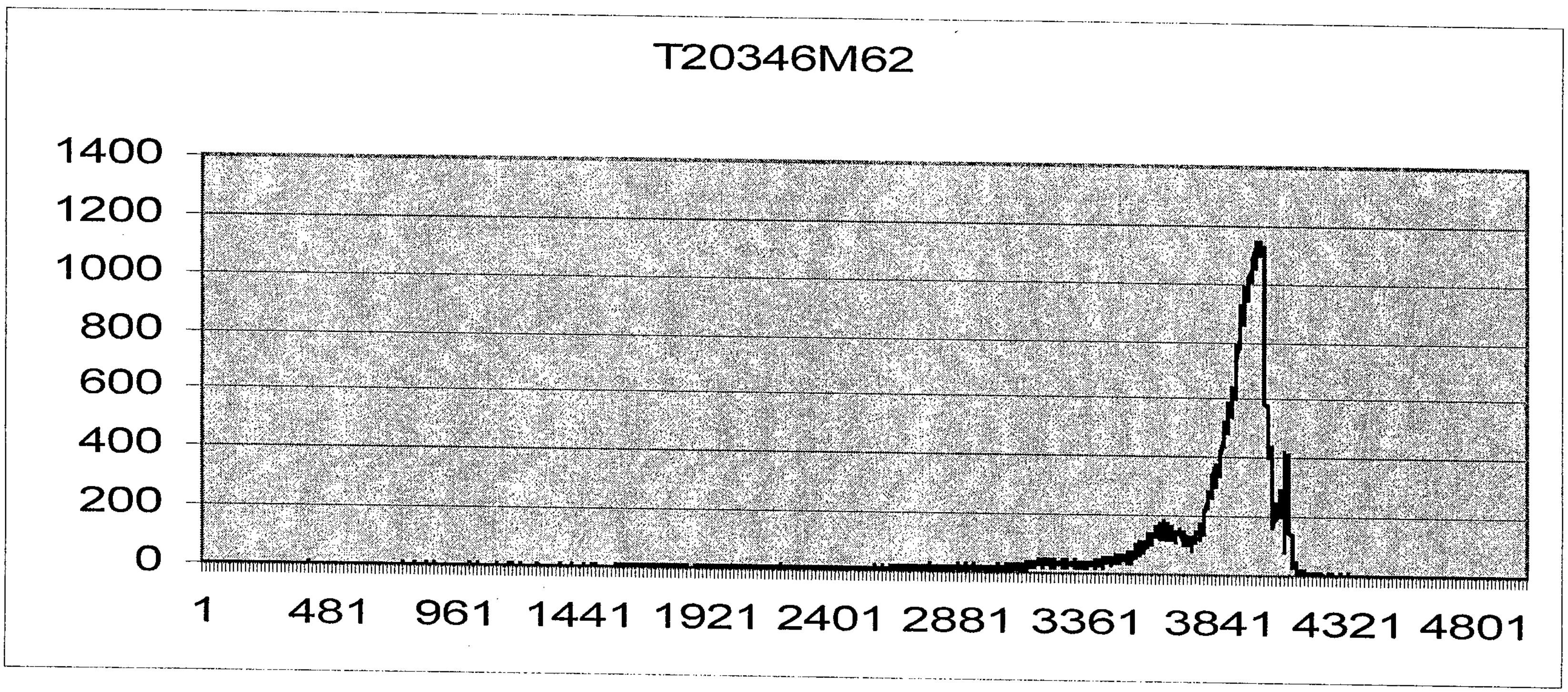
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

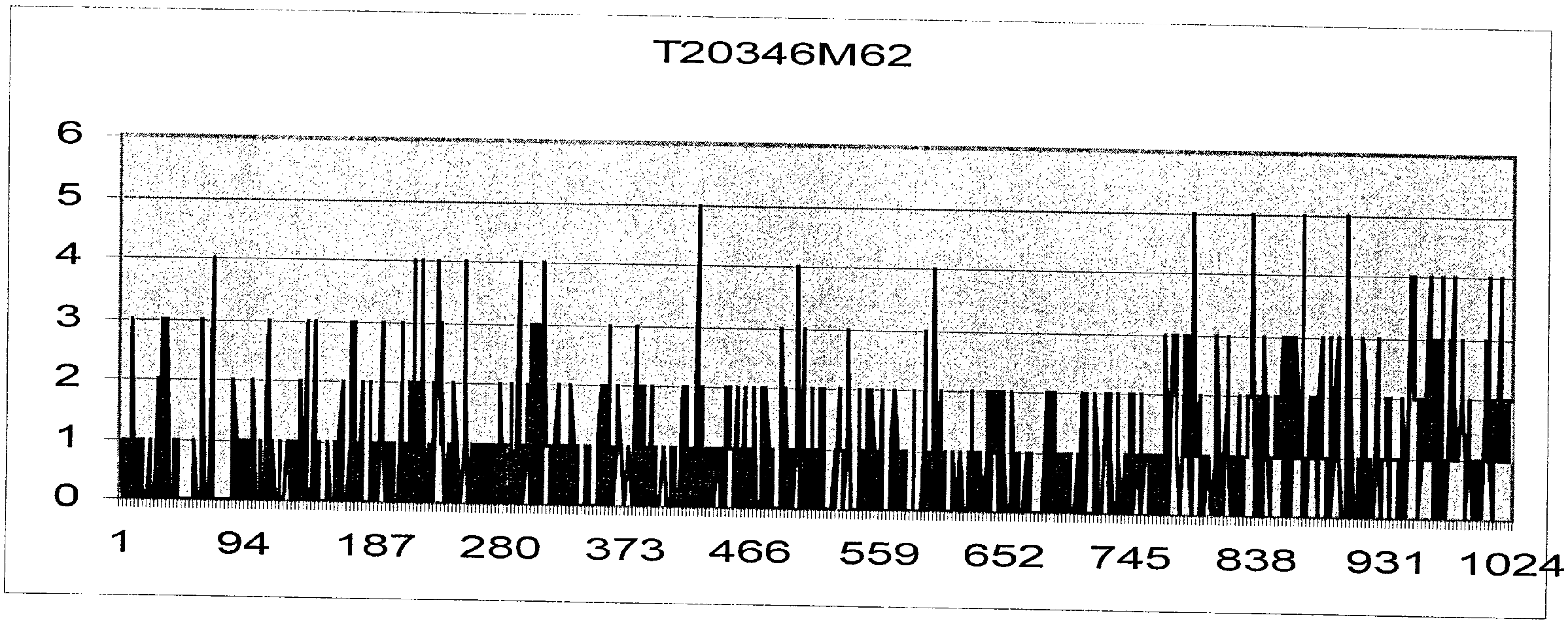


ELECTRONIC WARFARE CONCEPTS
EVALUATION PROGRAM
(RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS



ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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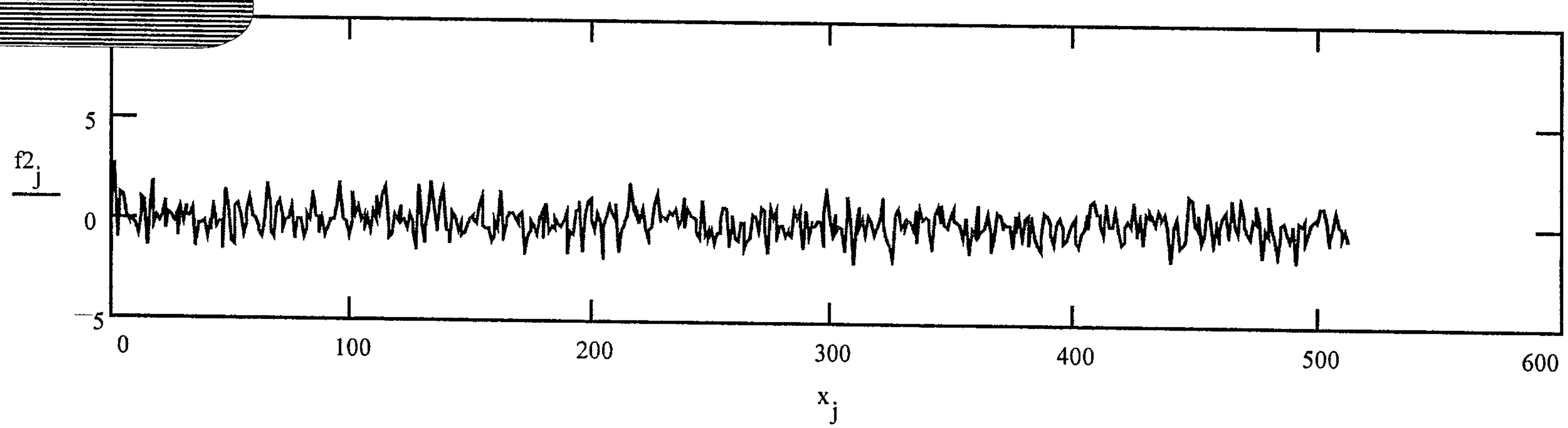
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

FFT of detrended data



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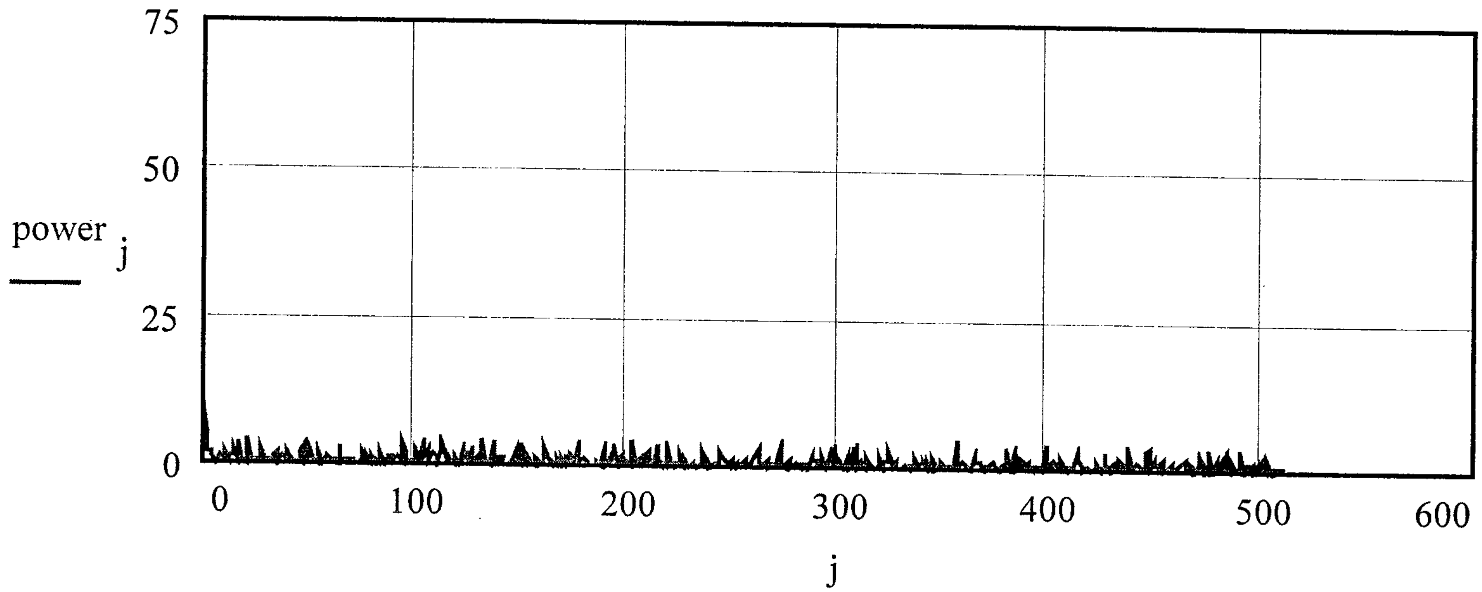
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

$$\text{power} := \overrightarrow{\left(\left|\text{fft}(y)\right|\right)^2}$$



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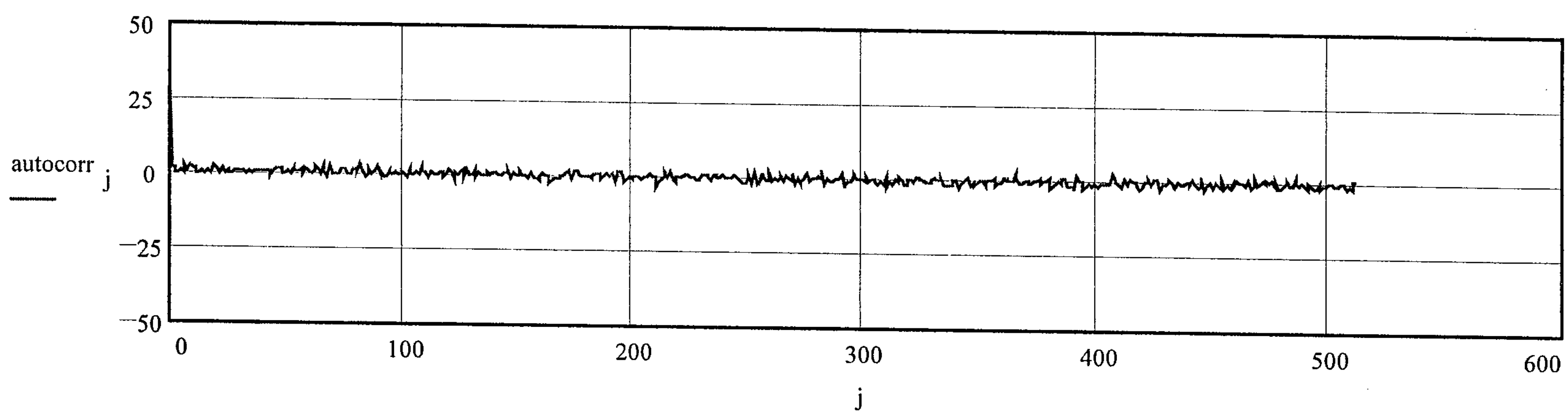
RESEARCH

RESEARCH PROGRESS

$autocorr := ifft(power)$



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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47
DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

Degree of Polynomial	k:=2
Number of data points	n:=rows(x)
Perform Polynomial Regression	z:=regress(x,v,k)
Define Interpolation Function	fit(q):=interp(z,x,v,q)

$$\text{Rsquared} := \frac{\sum \overrightarrow{\left[(\text{fit}(x) - \text{mean}(v))^2 \right]}}{\sum \overrightarrow{\left[(v - \text{mean}(v))^2 \right]}} = 0.057$$

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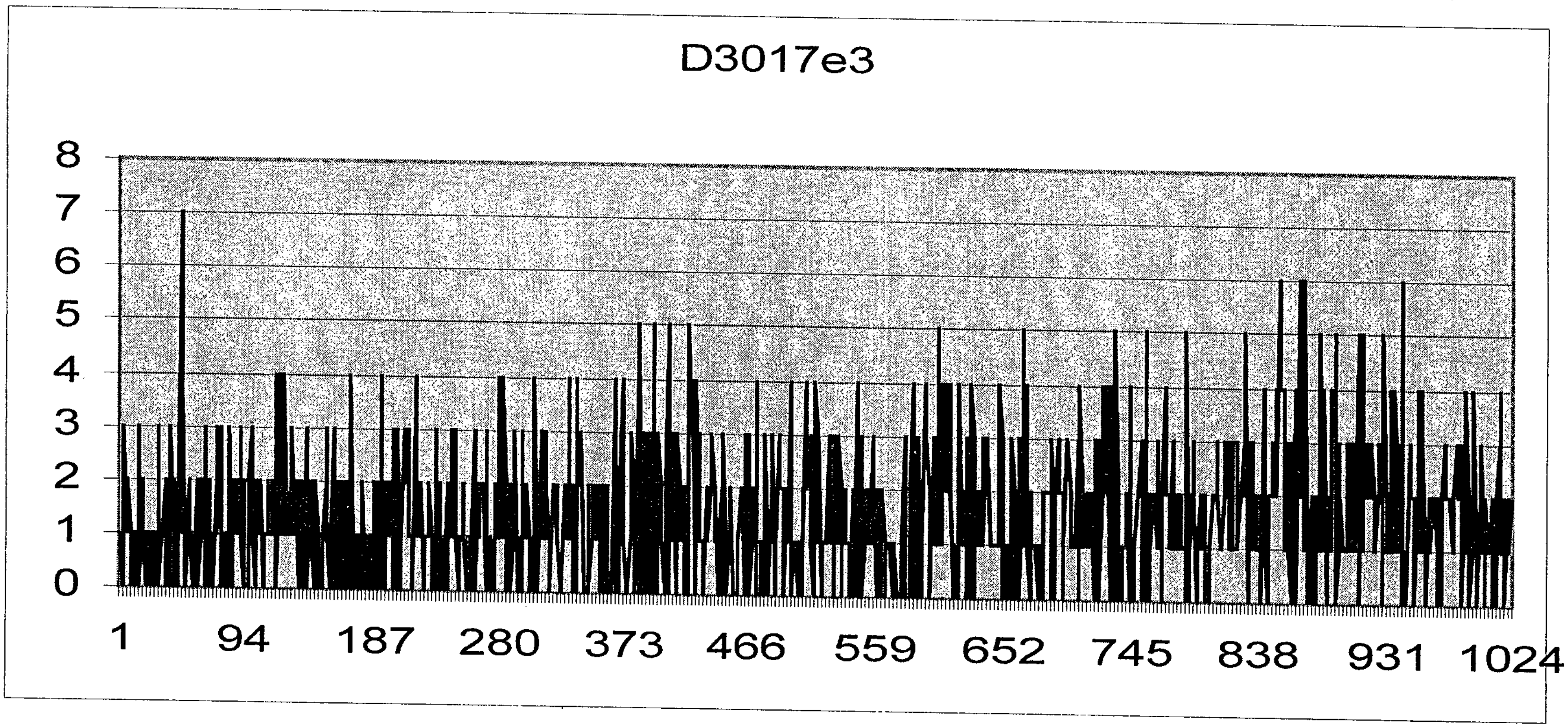
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS



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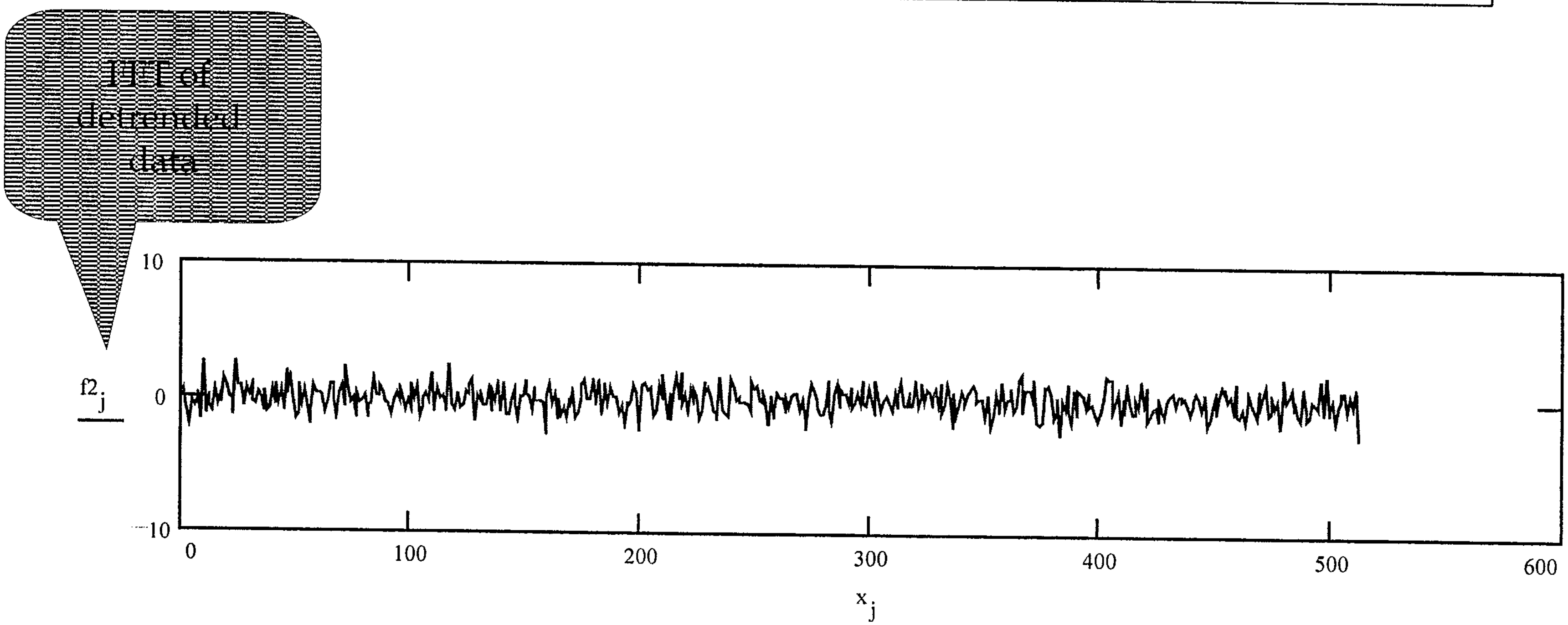
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS



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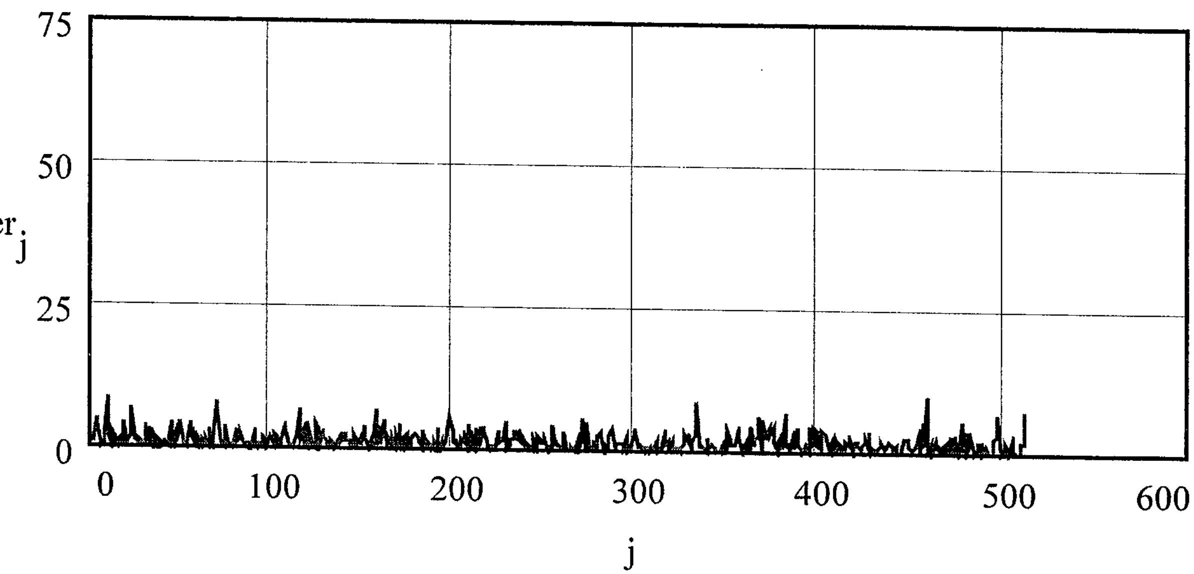
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

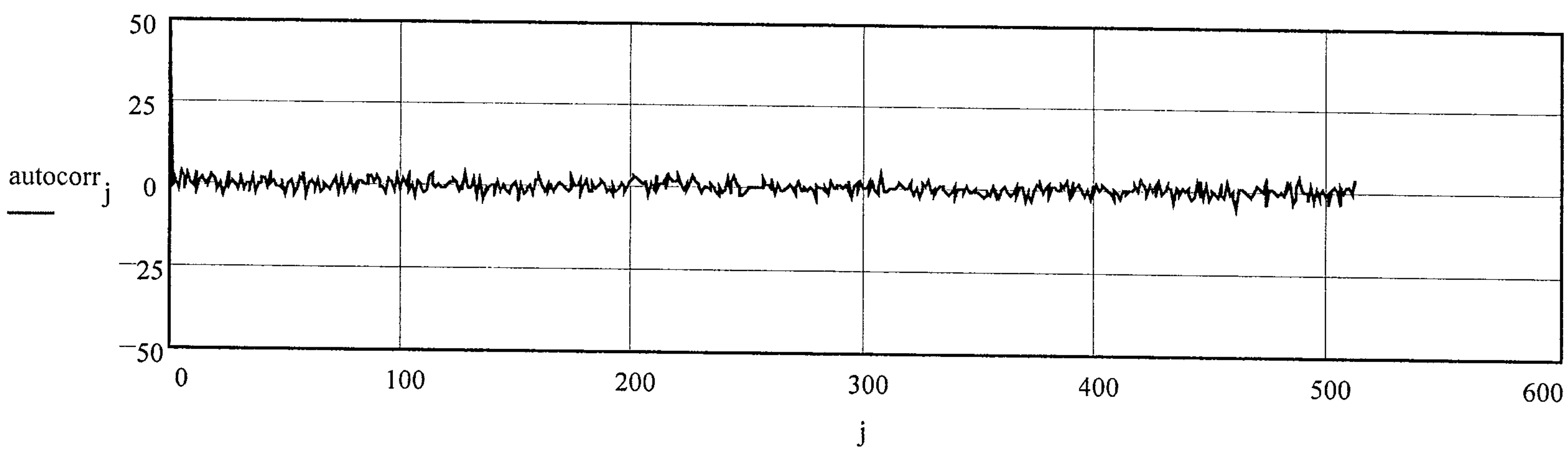
RESEARCH PROGRESS

$$power := \left(\overrightarrow{\left|fft(y)\right|}\right)^2$$



RESEARCH PROGRESS

$autocorr := ifft(power)$



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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

RESEARCH PROGRESS

Degree of Polynomial	k:=2
Number of data points	n:=rows(x)
Perform Polynomial Regression	z:=regress(x,v,k)
Define Interpolation Function	fit(q):=interp(z,x,v,q)

$$\text{Rsquared} := \frac{\sum \overrightarrow{\left[(\text{fit}(x) - \text{mean}(v))^2 \right]}}{\sum \overrightarrow{\left[(v - \text{mean}(v))^2 \right]}} = 0.035$$

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA RESEARCH PROGRESS REPORT

SUMMARY

★ Insufficient signal strength of threat at critical time before impact.

- Several threats are not much above background noise at this time.

★ False alarms exhibit R^2 characteristics and similar DSP characteristics to threats.

SUGGESTIONS FOR FURTHER WORK

- ★ Improve critical time value if possible so that more signal can be analyzed before classification.
- ★ Add Spectroscope capabilities to help in classification.

5.1.6 Presentation by Kerwin R. Holmes

The student briefing presented by Kerwin R. Holmes at this meeting is reproduced on the next 11 pages.

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Kerwin R. Holmes
MSEE Program
05/12/1999

RESEARCH PROPOSAL PRESENTATION

Kerwin R. Holmes
WR-ALC/LYSKS
JSTARS Electronic Engineer

Background and Experience:

Education:	BSEE degree from NC Agriculture and Technical State University Greensboro, NC 8/89
	Pursuing MSEE - completed 24 hrs. - 33 hrs. required - GPA 3.62
WR-ALC:	JSTARS Software Engineer

Research Topic:

APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

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Kerwin R. Holmes
MSEE Program
05/12/1999

APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

PROBLEM STATEMENT

- A better system security architecture is needed for preventing signal blockage, improving measures to guard against jamming of GPS signals.
- The GPS signal is weak and susceptible to interference (particularly in urban areas or regions where there are a lot of trees). This will also effect Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS).

Kerwin R. Holmes
MSEE Program
05/12/1999

APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

PROPOSAL JUSTIFICATION

★ Applicability to Mercer University MSEE Program

- Error Control Coding (ECC) is a complex subject requiring an understanding of Abstract Algebra.
- ECC is a key signal processing technique that is almost universally applied in digital communication / digital recording systems.
- The results will be publishable.

★ Applicability to the USAF

- ECC are used frequently for military and commercial satellite programs.
- In harsh jamming environments, ECC (e.g.,Reed-Solomon codes) can be applied to reduce the effect of jamming by correcting burst errors caused by the jamming interference.

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Kerwin R. Holmes
MSEE Program
05/12/1999

APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

PROPOSED RESEARCH OBJECTIVES

★ Determine a method for selecting an ECC.
- Investigate various coding schemes.
- Determine and identify the application requirements for selecting a coding scheme.
- Determine and identify the most suitable coding scheme for the application.

★ Determine the parameters of the identified ECC
- Error performance in relation to interference.
- Determine and identify software package for simulation of the system.

Kerwin R. Holmes
MSEE Program
05/12/1999

APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

PROPOSED METHOD OF INVESTIGATION

★ Upon selection of coding scheme.
- Interface the ECC method for GPS Development.
- Utilize GPS software simulation.
- Utilize ECC software simulation.
- Interface results.

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MSEE Program
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APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

PROPOSED SCHEDULE

- ★ Summer QTR 99
  - Preliminary Thesis Preparation. (June 21 - Jul 20)
  - Determine a method for selecting a code scheme. (Jul 21 - Aug 23)
- ★ Fall QTR 99
  - Determine and identify the code scheme. (Aug 24 - Oct 23)
  - Error performance for interference. (Oct 23 - Dec 20)
- ★ Winter QTR 00
  - Determine and identify software package (Jan 6 - Mar 17)
- ★ Spring QTR 00
  - Analyze and Interface results (Mar 18 - June 20)
  - Preliminary Presentation (June 21)

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MSEE Program
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APPLICATION OF ERROR CONTROL CODING FOR GPS DEVELOPMENT

PROPOSED SCHEDULE

- ★ Summer QTR 00
  - Utilize software simulation (June 22 - Jul 20)
  - Preliminary Thesis. (Jul 21 - Aug 23)
- ★ Fall QTR 00
  - Finalize the results (Aug 24 - Oct 23)
  - Finalize Thesis. (Oct 23 - Dec 20)
- ★ Winter QTR 01
  - Submit Thesis. (Jan 6 - May 17)
  - Final Presentation (May 18)

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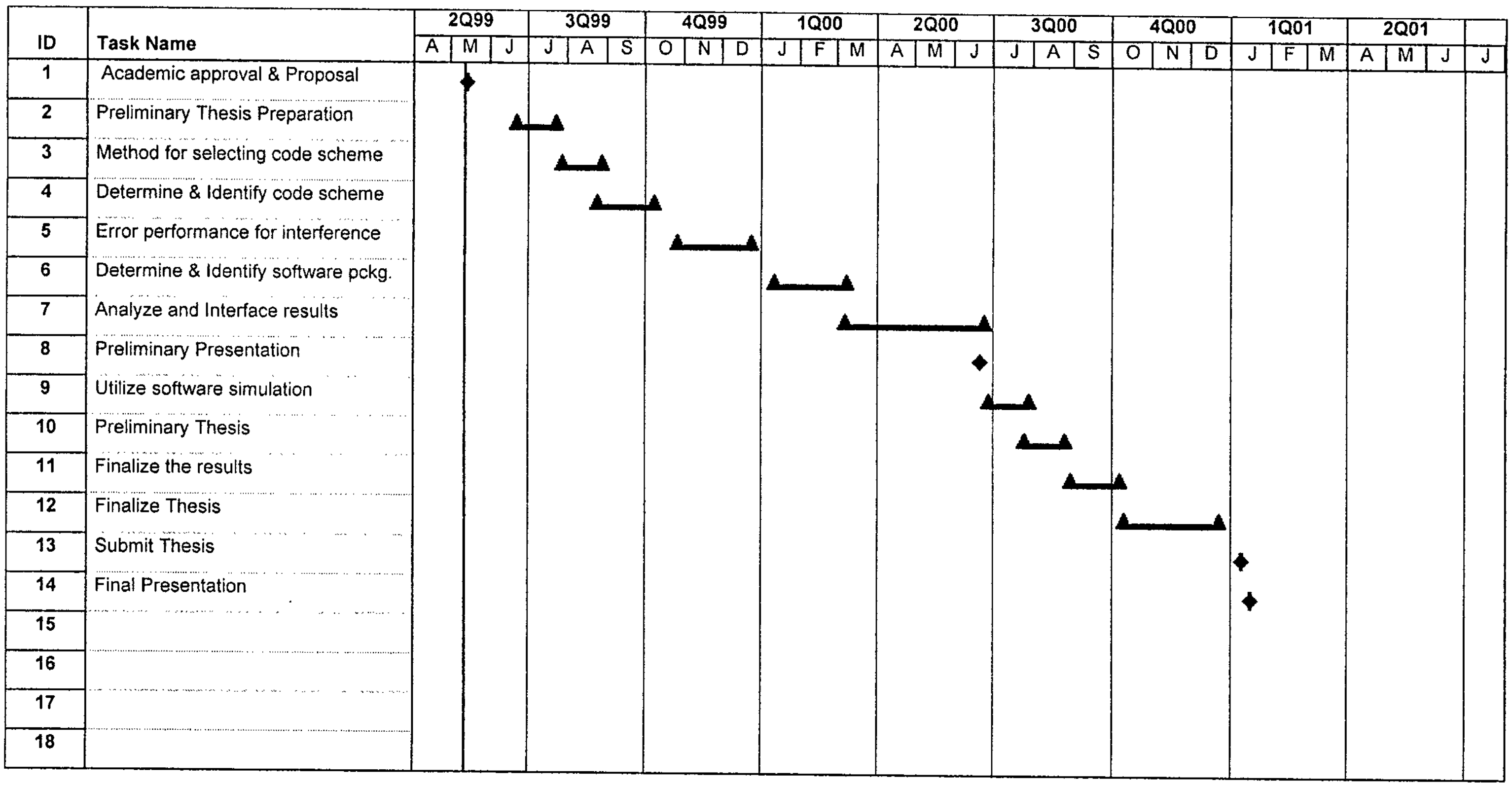

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MSEE Program
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Technical Support

In accordance with the Digital Communication II Class Lecture

★ Interleaved Reed-Solomon code may generate burst error correcting capabilities far beyond the burst error correcting capability of the original RS code.

★ Burst error are dominant mode of errors in:
- Multipath Fading Channels
- Jamming Channels
- Storage Systems:

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INTERLEAVING

Symbols read in by rows where 1 is read in first, then 2, and so forth.

........25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150

Symbols read out by columns and transmitted.

... 34 3 126 95 64 33 2 125 94 63 32 1

DE-INTERLEAVER

Symbols read in by columns.

... 34 3 126 95 64 33 2 125 94 63 32 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150

Symbols read out by row and sent to the Reed-Solomon decoder:

........25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

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MSEE Program
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Without block interleaving: (Ten symbol errors for each codeword)

Burst error

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

With block interleaving: (Two symbol errors for each codeword)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150

Symbols read out and transmitted:

...79 48 17 140 109 78 47 16 139 108 77 46 15 138 107 76 45 14 .... 34 3 126 95 64 33 2 125 94 63 32 1

Symbols after de-interleaving:

......50 49 48 47 46 45 44 43 42 4140 ....31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 1514 13 12 11 10 9 8 7 6 5 4 3 2 1

81 80 79 78 77 76 75 74 73

5.1.7 Presentation by Mark Napier

The student briefing presented by Mark Napier at this meeting is reproduced on the next 16 pages.

RESEARCH PRESENTATION

David M. Napier

Scientific Atlanta
ASIC Engineer, Digital Subscriber Group

Background and Experience:

Education: BSCPE from North Carolina State University.
Pursuing MSEE with emphasis in Digital Communications - 26 Semester hrs. completed.

Scientific Atlanta:
Digital and Analog Electronics Design, ASIC design and test.

Research Topic:

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
5/12/1999

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROBLEM STATEMENT

A proposed aircraft collision avoidance scheme uses the existing civilian IFF system. The technique uses the Mode S signaling scheme but defines a new message. The GPS position and velocity along with barometric altitude are transmitted instead of aircraft ID.

The new message is 112 bits long, 40 of which have been reserved for FEC coding. The proposed FEC scheme is a 5 bit t=4 Reed-Solomon code, RS(31,23). The proposed work is to analyze this scheme to determine the reliability improvements to be realized from the RS code. A decoder will be designed, implemented and tested in Verilog.

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Mark Napier
Presentation
5/12/1999

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROPOSAL JUSTIFICATION

★ Applicability to Mercer University MSEE Program
  - Digital Communication Classes Provide Material
  - RS Decoder Engine useful for other projects

★ Applicability to the USAF
  - Similar encoding could be used in Military IFF
  - Military aircraft could participate in the civilian system without revealing aircraft ID

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Presentation
5/12/1999

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROPOSED RESEARCH OBJECTIVES

- ★ Model the Mode S Modulation Scheme with RS
  - Verify that the Model Agrees with Analytical Predictions
  - Show that System Performance is Increased
- ★ Design the RS Decoder
  - Design the Decoder in Verilog
  - Verify with Verilog Testbench

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APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROPOSED METHOD OF INVESTIGATION

- ★ Implement RS Decoder in Verilog
- ★ Model the IFF Mode S Modulation Scheme
  - Literature Search and Analysis
  - Model Development and Verification
- ★ Model the System with RS FEC coding
  - Model without Erasure Information
  - Model With Erasure Information

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

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5/12/1999

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROPOSED SCHEDULE

★ Summer Semester

- Search literature for any previous work on PPM signaling characteristics.
- Provide analysis as a basis for model.
- Develop and verify PPM model.
- Simulate in presence of fading with and without RS coding.
- Develop and test decoder for RS(31,23) code.
- Document results and submit project report.

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APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

TECHNICAL PRESENTATION

The civilian aircraft transponders are based on a WWII IFF (Information Friend or Foe) system. It is intended for ground based ATCRBS (Air Traffic Control Radar Beacon System) use and in general no information is available to aircraft not using air traffic control services. TCAS provides major air carriers with collision avoidance information but is an expensive system that has very limited capacity. A distributed collision avoidance system using GPS(Global Positioning System) would be inexpensive and highly reliable.

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The current system interrogates aircraft on 1030 MHz. The transponders respond on 1090MHz with mode 3A (squawk code), mode C (squawk altitude), or various mode S (squawk ID) messages depending on the interrogation sequence received and the transponder's capability. It transmits at a peak power output of 250 Watts. It uses pulse shaping such that the transmitted power at plus or minus 25MHz is down by 60 dB [TSO C74C]. The receiver circuit has a threshold sensitivity of -70 dBm.

A proposed scheme[1] would use current transponder technology to transmit at random intervals GPS position and velocity along with barometric altitude in addition to the normal mode 3A/C responses. If widely used, any aircraft with a compatible receiver could have a cockpit display showing other aircraft in the area. The new system has been named "Tail Light", analogous to the tail light in a car at night or in the fog.

The proposed system would use the mode S downlink format signaling which is a PPM(Pulse Position Modulation) scheme with a 1 Mbit/s rate. A "1" is defined to be a 0.5us burst followed by 0.5us of off time. A "0" is defined to be 0.5us of off time followed by a 0.5us burst. The message is proceeded by a 8us sync pulse. Either 56 (single length) or 112 (double length) bits of data follow.

For the double length message, 40 bits have been assigned for Forward Error Correction (FEC) using Reed-Solomon encoding. Since this is a short message, the optimal burst error capability is obtained[2] with a 5 bit t=4 or RS(31,23) code. This code can correct a 16 bit worst case burst error.

Also, if erasure information can be provided by the receiver a burst error of 36 bits can be corrected effectively doubling the error correction capability[3]. Note that with PPM a simple system for obtaining erasure information is available. Since "00" and "11" are not defined, any bit received with these sequences should be flagged as an erasure. As these bits are arranged into 5 bit words for the decoder, the word would be marked as an erasure.

In conclusion, the proposed system would be a benefit for general aviation which lacks a cost effective solution for collision avoidance. The FEC scheme proposed would greatly enhance overall system reliability. Lastly, the RS(31,23) decoder would be useful for any mobile system that uses short (61-155 bits) bursts of data.

References:

[1] Peshak, B. Keith; http://www.monarch-air.com/gaviation/

[2] B. Kamali, "Some new Outlooks on Burst Error Correction Capabilities of Reed-Solomon Codes with Applications in Mobile-Communications", Proceedings of IEEE VTC'98, Ottawa, Canada, May 1998, pp. 343-347.

[3] S. Lin & D. J. Costello, "Error Control Coding: Fundamentals & Applications", Prentice Hall, 1983.

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Mark Napier
Presentation
5/12/1999

Mode A Packet - Four digit squawk code from front panel is encoded in octal form.

Bit	Description
F1	1st Framing Bit - 1
C1	3rd Digit 1's Value
A1	1st Digit 1's Value
C2	3rd Digit 2's Value
A2	1st Digit 2's Value
C4	3rd Digit 4's Value
A4	1st Digit 4's Value
X	No Transmit - 0
B1	2nd Digit 1's Value
D1	4th Digit 1's Value
B2	2nd Digit 2's Value
D2	4th Digit 2's Value
B4	2nd Digit 4's Value
D4	4th Digit 4's Value
F2	2nd Framing Bit - 1
X	No Transmit - 0
X	No Transmit - 0
SPIP	Special Purpose ID Pulse; Front Panel Ident. Button.

Mode C Packet - Identical to Mode A packet. Altitude encoded on 10 bits of the digit values.

Mode S Sync Pulse.

Time	Value
0 - 0.5 US	1
0.5 - 1.0 US	0
1.0 - 1.5 US	1
1.5 - 3.5 US	0
3.5 - 4.0 US	1
4.0 - 4.5 US	0
4.5 - 5.0 US	1

Tail Light Long Format Message, 112 bits.

Field	Length	Description
Preface	5 bits	TBD, possible DF26 or 11010 base 2.
Latitude	16 bits	Ones of degrees, minutes and tenths (DMM.M). Precision is 0.1 minutes = 600 feet. Period is 9 degrees, 59.9 minutes = 600 NM. The second byte, tens of minutes, only ranges from 0 through 5, thus doesn't use the MSB. Set that bit to 0 for north, and 1 for south. 4 numbers, 16 bits.
Longitude	16 bits	Similar to latitude. Set the MSB of the tens of minutes byte to 0 for west and 1 for east. From 70 through 80 degrees latitude send tens of degrees through whole minutes (DDMM). Above 80 degrees send whole degrees and tens of minutes (DDDM). 4 numbers, 16 bits.
Altitude	10 bits	From Altitude Encoder.
Speed	12 bits	000-999 knots. If the craft is traveling over 999 knots, send 999, don't blindly drop the leading byte and send 000. 3 numbers, 12 bits.
Course	12 bits	000-359 degrees true. Use the otherwise unused MSB of the hundreds of degrees to include the message validity flag. 3 numbers, 12 bits.
Stuff Bit	1 bit	TBD
FEC Parity	40 bits	RS(31,23) code. 5 bit symbols, t = 4.

Tail Light Short Format Message, 56 bits.

Field	Length	Description
Preface	5 bits	TBD, possible DF27 or 11010 base 2.
Latitude	12 bits	Minutes and tenths (MM.M). Precision is 0.1 minutes = 600 feet. Period is 59.9' = 60 NM. The first byte, tens of minutes, only ranges from 0 through 5, thus doesn't use the MSB. Set that bit to 0 for north, and 1 for south. 3 numbers, 12 bits.
Longitude	12 bits	Similar to latitude. Set the MSB of the tens of minutes byte to 0 for west and 1 for east. From 70 through 80 degrees latitude send ones of degrees through whole minutes (DMM). Above 80 degrees send whole degrees only (DDD) and put the E/W bit in the otherwise unused first bit of the hundreds of degrees. 3 numbers, 12 bits.
Altitude	10 bits	From Altitude Encoder.
Speed	8 bits	10 knots precision, up to 990 knots. 2 numbers, 8 bits.
Course	8 bits	10 degrees precision, 000-350 degrees true. Use the otherwise unused MSB of the hundreds of degrees to include the validity flag. 2 numbers, 8 bits.
Parity	1 bit	Single parity bit for message.

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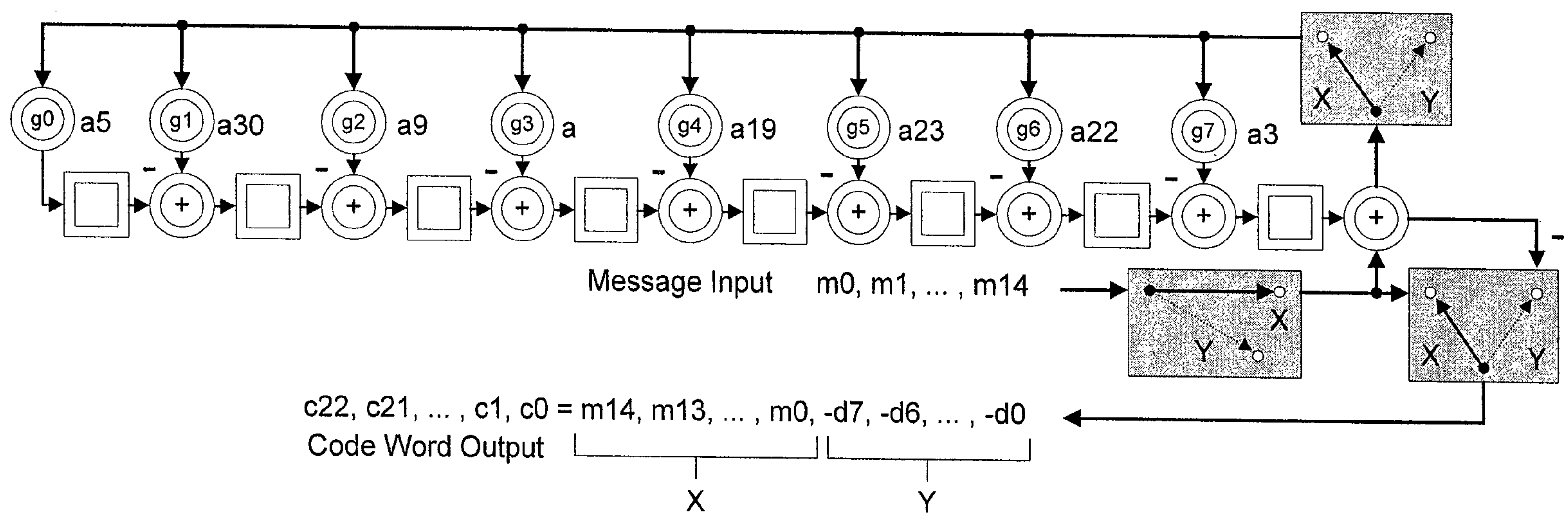
Mark Napier
Presentation
5/12/1999

Reed Soloman (31,23) Encoder (Shortened)

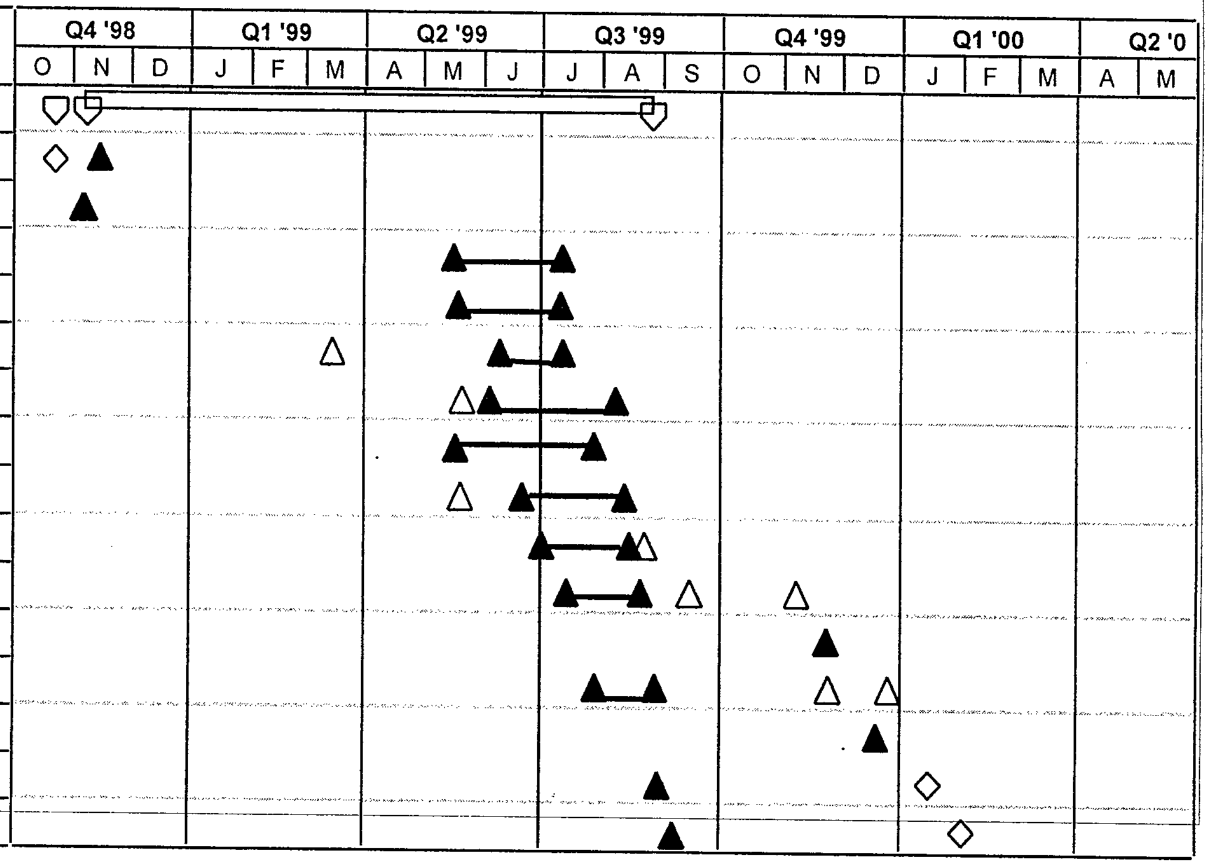


RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
5/12/1999

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

ID	Task Name
1	**A. Student - Master's Project Activity**
2	Academic approval
3	RAPCEval proposal presentation
4	Literature Search for PPM Signaling
5	Develop equations/relationships
6	Develop and verify PPM model
7	Simulate with fading and RS Coding
8	Develop and test RS decoder
9	Develop plots/Illustrate findings
10	Finalize research information
11	Preliminary project report preparation
12	Final RAPCEval presentation
13	Complete written project report
14	Schedule graduation (campus)
15	Project committee defense
16	Submit project report to university



5.2 Steering Committee, August 1999

5.2.1 Meeting Minutes

RF/Receiver and Processing Concepts Evaluation Program Program Research Standards Committee Meeting Minutes 19 August 1999

A RAPCEval Steering Committee Meeting was convened at Mercer Engineering Research Center on August 19, 1999.

An overview by Dr. Tom Bass included a list of students who have successfully completed the program. The list included the publications of each student and the document retrieval number for access. Also included was a list and brief description of the research efforts of ongoing RAPCEval students.

Dr. David Barwick, MERC's executive director, followed, with a welcome to the group and also a discussion of the background and goals of the newly hired dean of the Mercer University School of Engineering. The new dean is coming to Mercer from Auburn University, and will be fully on board in mid September.

Three student presentations were scheduled for this meeting. One student was required to make an unavoidable trip that conflicted with our meeting, so two students briefed the group. Both students are under the direction of Mercer's Dr. Behnam Kamali.

Mr. Benjamin Henderson delivered a scaled-down version of his briefing he delivered to an International communications conference in Vancouver, B.C., this summer. The talk outlined a novel neural network technique for deciding on the best Reed-Solomon data correcting code specification for various data corruption situations.

Mr. Houston Jones gave an update on his project to apply Reed-Solomon data correcting codes to communication influenced by fading problems. He pointed out correction requirements for fading caused by interference with varying degrees of Doppler shift. Houston has been provided with newly available communication simulation software (Avalon).

A round of general discussion followed the student presentations. The first topic addressed changes in the committee membership because of a member retiring or becoming otherwise unavailable. Tom Bass took an action item to send an invitation letter to Mr. Aaron Linn of AFRL/SN to replace committee member Paul Westcott. Tom will also generate a plaque to thank Paul for his service on the steering committee.

A suggestion was made by Phil Oliver that the RAPCEval group might want to take advantage of video conferencing. Phil proffered an invitation to hold the next meeting at WR-ALC, where the

conferencing capability has been quite adequate for ongoing groups. Ches Rehberg commented that face-to-face is probably better for start-up meetings. Another suggestion relayed the wisdom of having graphics such as slides or drawings sent ahead via email or other means. This allows the conferencing bandwidth to be devoted to the audio and video of the conference surroundings.

Further discussion addressed the importance of more clearly specifying the relevance of student research to the Air Force. Relevance needs to be established *before* the student becomes heavily involved in the research. A certifiable connection of the research to our sponsoring organization at AFRL must be established for ongoing support of the research. Connections between Clayton Paul at Mercer (specializes in electromagnetics) and Steve Schneider (AFRL), between Behnam Kamali at Mercer (specializes in communications) and Jim Stephens (AFRL), and between Paul MacNeil at Mercer (software engineering) and Jim Tsui (AFRL) need to be enhanced by further communication of ongoing AFRL research and goals.

In line with this objective, a suggestion was made for RAPCEval personnel to make an *annual* request for topics. Dave Barwick will get a contact point.

Tom Bass will address a final suggestion, that the Advanced Digital System (ADS) program be queried for possible research topics.

5.2.2 Meeting Agenda

Agenda

RAPCEval program

INTERIM STEERING COMMITTEE MEETING

99 Aug 19 — 1:30 PM to 4:15 PM
Conference Room, Mercer Engineering Research Center
135 Osigian Boulevard, Warner Robins, GA

Meeting called by: Nicholas Pequignot, AFRL/SNRP, Air Force Research Laboratory Program Manager

Facilitator: Dr. Tom Bass

Committee Members:

AF Research Laboratory	Robins AFB	Mercer University
Mr Nicholas A Pequignot	Mr Steve Strawn	Dr David Barwick
Mr Emil R Martinsek	Mr John LaVecchia	Dr Tom Bass
Mr Norman A Toto	Mr Phil Oliver	Dr Aaron Collins
Dr Duane A Warner	Mr Ches Rehberg	Dr Behnam Kamali
Mr Paul J Westcott	Mr. Larry Sheets	Dr Paul MacNeil

Email addresses:

AF Research Laboratory	Robins AFB	Mercer University
Nicholas.Pequignot@sn.afrl.af.mil	Steve.Strawn@robins.af.mil	dbarwick@merc.mercer.edu
Emil.Martinsek@sn.afrl.af.mil	John.Lavecchia@robins.af.mil	tbass@merc.mercer.edu
Norman.Toto@sn.afrl.af.mil	Ches.Rehberg@robins.af.mil	collins_as@mercer.edu
Duane.Warner@sn.afrl.af.mil	Larry.Sheets@robins.af.mil	macneil_pe@mercer.peachnet.edu
Paul.Westcott@ sn.afrl.af.mil		kamali_b@mercer.peachnet.edu

Schedule

Greetings	Dr David Barwick	1:30 PM – 1:35 PM
Meeting Overview	Dr Tom Bass	1:35 PM - 1:45 PM
Student Presentations		
Selection of the Most "Efficient" Reed-Solomon Code for a Specific Application Using Neural Networks	Mr. Henderson Benjamin	1:45 PM – 2:15: PM
Additional Profit-able Analysis of UV Signals as collected by WR-ALC	Mr. Steve Boswell	2:15 PM – 2:45: PM
Evaluation of Reed-Solomon Codes for CDMA Systems	Mr. Houston Jones	2:45 PM – 3:15 PM
Discussions & New Business	Dr. Tom Bass	3:15 PM – 4:30 PM
Adjourn		4:30 PM

5.2.3 Attendance Roster

The attendees at this meeting are listed here:

ID	Name	Organization	Phone	Email Address
1	Tom Bass	MERC	912-953-6800	bass_wt@mercer.edu
2	Paul MacNeil	Mercer	912-752-2185	macneil_pe@mercer.edu
3	Charles Bass	MERC	912-953-6800	Cbass@merc.mercer.edu
4	Rudy Shaw	MERC	937-251-8656	r.shaw@worldnet.att.net
5	Henderson Benjamin	WR-ALC	912-327-2864	henderson.benjamin@robins.af.mil
6	Tony White	AFRL/SWRP	937-255-6127	anthony.white@sn.afrl.af.mil
7	Dave Barwick	MERC	912-953-6800	dbarwick@merc.mercer.edu
8	Behnam Kamali	Mercer	912-752-2415	kamali_b@mercer.edu
9	Ches Rehberg	WR-ALC/LNEX	912-936-4525	ches.rehberg@robins.af.mil
9	Mark Napier	Scientific Atlanta	770-903-6980	mark.napier@subasic.sciatl.com
10	RP (Phil) Oliver	WR-ALC/LNERT	912-926-2588	oliver@ec.robins.af.mil
11	Nicholas Pequignot	AFRL/SNRP	937-255-6127, Ext. 4235	nicholas.pequignot@sn.afrl.af.mil
12	Houston Jones	WR-ALC/QLYM	912-926-0144	jhjones@hom.net

5.2.4 Overview of the Program (Dr. Bass)

The Overview Briefing of the RAPCEval Program as presented at this meeting is reproduced on the next 13 pages.

RAPCEval STEERING COMMITTEE MEETING

August 19, 1999

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

August 1999

GENERAL PROGRAM INFORMATION

- ★Contract: F09603-93-G-0012-0017
- ★Customer: Air Force Research Laboratory, Sensors Division (AFRL/SN)
- ★Contract Value: $349,964

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

August 1999

PROGRAM STATUS

- ★Graduate Research Jointly Supported by Mercer, AFRL, WR-ALC, and Industry
- ★Thirteen successful research projects (with Masters' degrees) have been completed
- ★Seven ongoing research projects

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

August 1999

PROGRAM STATUS

- ★ Research has been approved by the steering committee to be useful to the Air Force
- ★ Research has been found to have academic merit by the university and by the committee

PROGRAM STATUS

- ★ Research has been approved by the steering committee to be useful to the Air Force
- ★ Research has been found to have academic merit by the university and by the committee

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

August 1999

PROGRAM RESEARCH STANDARDS COMMITTEE MEMBERS

★ *AF RESEARCH LAB*

Nick Pequignot (PM)
Emil R. Martinsek
Norman A. Toto
Duane A. Warner
Paul J. Westcott

★ *MERCER UNIVERSITY*

Aaron Collins
Benham Kamali
Paul MacNeil

★ *WR-ALC*

Steve Strawn (PM)
John LaVecchia
Phil Oliver
Ches Rehburg
Larry Sheets

★ *MERC*

Dave Barwick (Chmn)
Tom Bass (PM)

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

August 1999

GRADUATES & REPORT REFERENCES

- ★ *Mark Astin,* "Application of Parallel Computing Techniques to the RAD Algorithm", (classified) AFRL-SN-WP-TR-1998-1088
- ★ *Henderson Benjamin,* "Selection of Reed Solomon Codes Using Neural Networks", AFRL-SN-WP-TR-1998-1056, p. 131
- ★ *Ron Brinkley,* "Burst Error Correction with Reed-Solomon Codes" to be included in forthcoming RAPCEval annual report (Fall, 1999)

GRADUATES & REPORT REFERENCES

- ★ *Mark Campbell,* "Auto-Regressive Spectral Analysis - EW Applications", WL-TR-94-1057
- ★ *Randy Ford,* "Passive Location via Evolutionary Genetic Algorithms", forthcoming report, ~ 12/99
- ★ *Claus Franzkowiak,* "Four-Pulse Primary RAD Filter Development", (classified) AFRL-SN-WP-TR-1998-1087

GRADUATES & REPORT REFERENCES

- ★ *Neal Garner*, "Error Correction and Prediction for Improved Communication of Time and Time Measurements", WL-TR-96-1161
- ★ *Joseph Kelley* , " A Parameter Determination Alternative for RAD Analysis", (classified) WL-TR-95-1005
- ★ *Joseph Kelley*, "MultiGroup Simultaneous RAD Parameter Selection", (classified) WL-TR-97-1094

GRADUATES & REPORT REFERENCES

- ★ *Max Roesel,* "Agile RF/PRI Radar Analysis via RAD", (classified) WL-TR-95-1020
- ★ *Dave Schuler,* "Comparison of Algorithms for Geolocation of Radar Signals", WL-TR-96-1161
- ★ *Tracy Tillman,* "Hardware Implementation for an Advanced Pulse Processing Algorithm", (classified), AFRL-SN-WP-TR-1998-1085

GRADUATES & REPORT REFERENCES

★ *Kirk Wright*, "Object Oriented Modeling of the AN/ALQ-172", (classified) AFRL-SN-WP-TR-1998-1086

TODAY'S STUDENT PRESENTATIONS

- ★ *Henderson Benjamin,* "Selection of the Most Efficient Reed-Solomon Code for a Specific Application Using Neural Networks"
- ★ *Houston Jones,* "Evaluation of Reed-Solomon Codes for CDMA Systems"
- ★ *Steve Boswell,* "Profitable Additional Analysis of UV Signals as collected by WR-ALC"

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

August 1999

ONGOING & PLANNED STUDENT RESEARCH

- ★ *Kerwin Holmes* - GPS Enhancement
- ★ *Mark Napier* - IFF Improvement
- ★ *Wes Stinehelfer* - Dr. Tsui GPS Project
- ★ *Peter Bryant* - Airframe/Missile Simulation and Modeling - SURVIAC/ Booz-Allen Hamilton

5.2.5 Presentation by Henerson C. Benjamin

The student briefing presented by Henderson C. Benjamin at this meeting is reproduced on the next 14 pages.

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

RESEARCH UPDATE

Henderson Benjamin
WR-ALC/LYSKS
JSTARS System Engineer

Date Approved: May 7, 1996

Projected Completion Date: April 2, 1998

Research Topic: *NEURAL NETWORKS SYSTEM THAT SELECTS REED-SOLOMON CODES FOR A SPECIFIC APPLICATION*

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

Henderson C. Benjamin
MSEE Program
August 1999

NEURAL NETWORKS SYSTEM THAT SELECTS REED-SOLOMON CODES FOR A SPECIFIC APPLICATION

- Problem Statement
- Objective
- Reed-Solomon Codes
- Neural Networks
- Research Results
- International Conference on Communication 1999

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

Henderson C. Benjamin
MSEE Program
August 1999

PROBLEM STATEMENT

Reed-Solomon codes are powerful error control coding due to their ability to detect and correct random and burst errors. Reed-Solomon codes are maximum distance separable codes which mean they provide the best error correction capability relative to the number of overhead symbols that is required. Because of the large number of Reed-Solomon codes to select from, it was determined that some means of Artificial Intelligence would be useful for selecting a Reed-Solomon code for a given application. Data will be collected and analyzed for Reed-Solomon codes and shortened Reed-Solomon codes with block interleaving. The goal of this thesis work is to develop a Neural Network which will select the best possible code for a particular application.

Henderson C. Benjamin
MSEE Program
August 1999

RESEARCH OBJECTIVES

- Determine the method for selecting Reed-Solomon codes
- Collect/Analyze Reed-Solomon Code Data
  - Collect/Analyze data for RS codes of length 7, 15, 31, 63, 127, and 255
  - Collect/Analyze additional data deemed useful to a designer
  - Develop Neural Network
- Collect/Analyze shortened Reed-Solomon Code Data
  - Collect/Analyze data for shortened RS codes of length 255
  - Collect/Analyze additional data deemed useful to a designer
  - Develop Neural Network

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

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MSEE Program
August 1999

REED-SOLOMON CODES

- Reed-Solomon (RS) Codes are the most widely applied channel codes in digital communication and digital storage systems.

- First Practical Application in NASA's Voyager deep space communications system.

- RS codes are currently found in satellite and space communications, compact disk, CD ROM, DTV, HDTV, wireless mobile communication networks, ATM networks, and DVD.

- Reed-Solomon codes are powerful error control coding due to their ability to detect and correct random and burst errors. Reed-Solomon codes are Maximum Distance Separable (MDS).

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

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August 1999

REED-SOLMON CODES

- The catalog of RS codes are rather long if modified RS codes, interleaving RS codes, and product RS codes are added to the list.
- Designers of are faced with numerous tables, graphs, and equation when determining the best RS code for an application by hand.
- Artificial Intelligence can assist in selecting the best RS code for a specific application.

Henderson C. Benjamin
MSEE Program
August 1999

REED-SOLOMON CODES

- Reed-Solomon Codes are generated using a polynomial generator.
- Code length (n), dimension length (k), symbol length (m), random burst error (t) correction capabilities, code rate (R_c), single burst error correction (b_1), double burst error correction (b_2), and triple burst error correction (b_3).
- The shortened codes are more manageable when developing codes and preferred because of the amount of redundancy

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

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August 1999

NEURAL NETWORKS

- A Neural Network is an approach to computing that involves developing mathematical structures with the ability to learn.

- The human brain has many features that are desirable in AI (fault tolerant and robust, very flexible; deals with fuzzy, probabilistic, noisy or inconsistent data; parallel, small, compact, and dissipates very little power.

- The current cycle time of a neuron is approximately a millisecond which is a million times slower than semiconductor gates.

- NNs are able to Generalize.

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MSEE Program
August 1999

NEURAL NETWORKS

- A Neural Network contains units which are analogous to neurons in the brain.
- The sigmoid function introduces nonlinearity into a network.
- A Neural Network contains processing element known as nodes, units, or artificial neurons.
- A Neural Network also contain weights that are connected to each node in the network.

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MSEE Program
August 1999

NEURAL NETWORKS

- A Backpropogation algorithms a nonlinear extension of the LMS algorithm. The LMS is similar to the Kalman filter.
- It is derived with iterative applications of the chain rule of differential calculus and embedded in a stochastic approximation framework.
- Levenberg-Marquardt (LM) is a variation of backpropogation method. It also utilizes an approximation of Newton's method.

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

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RESEARCH RESULTS

Neural Network Identification # 1: This NN is used when the designer specifies the hardware to be used and will result in the most efficient in respect to the code rate.

This is a six input system (m, t, R, b, b, b)

- The desired outcome is to determine the data length for the code. (k)
- The test data results were : 99.2 % Correct

  0.8 % Incorrect by 1 data length

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August 1999

RESEARCH RESULTS

Neural Network Identification # 2: The second NN selects the most efficient shortened Reed-Solomon code. The designer only requirement is to enter the percentage of the total number of words to be shortened.

This is a five input system $(\%s, t, \quad, b_1, b_2)\ b_3$

- The desired outcome is to determine the code and data length (n, k)
- The test data results were : 98.36% Correct for the code length
  84.40% Correct for the data length

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

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MSEE Program
August 1999

INTERNATIONAL CONFERENCE ON COMMUNICATION

- ICC '99 (Multimedia & Wireless) Vancouver, British Columbia, Canada 6 - 10 June 1999
- The purpose of the conference was to provide organizations with building blocks towards the rapidly emerging information age
- The conference was sponsored by the Communication Society of IEEE

RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM

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MSEE Program
August 1999

INTERNATIONAL CONFERENCE ON COMMUNICATION

- Abstract for the ICC '99 was Sep 98
  Selection of the Most "Efficient" Reed-Solomon Code for a Specific Application Using Neural Networks
- Notification of acceptance for the Mini Conference session Jan 99
- Approximately 1000 papers were submitted
- Approximately 1400 delegates and guest representing over 40 countries

5.2.6 Presentation by Steve Boswell

The student briefing presented by Steve Boswell at this meeting is reproduced on the next 22 pages.

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM
(RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

RESEARCH PRESENTATION

S. Boswell
ARINC, Inc./WR-ALC
Principal Analyst

August, 1999

Research Topic:

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

PROBLEM STATEMENT

To acquire AN/AAR-47 data and apply DSP techniques to the data. Then present the data to a Neural Network with a Fuzzy Logic Controller which speeds learning. The Neural Network will learn the difference between threats and false alarms.

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

PROPOSAL JUSTIFICATION

★ Applicability to Mercer University MSSS Program
- Applying AI and DSP techniques to a problem

★ Applicability to the USAF
- Determine if techniques will improve reliability of AN/AAR-47 to accurately determine targets

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH OBJECTIVES

★ Build/Acquire Neural Network
- Basic Back-Propagation Network
- Implement Fuzzy Logic Controller in NN
- Verify NN using standard XOR problem

★ Acquire/Analyze Data
- Observe Data peculiarities visually
- Pass data through various DSP techniques
- Train NN with DSP variables

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

METHOD OF INVESTIGATION

★ AN/AAR-47 Data Analysis
- Apply FFT to raw data
- Apply FFT to detrended data
- Apply Wavelet Transform to data
- Perform power analysis data
- Perform autocorrelation technique to data
- Place data into NN and try to train

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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA - Schedule/Actual

★ Semester 1
- Build NN
- Add FLC to NN
- Acquire data and perform preliminary analysis

★ Semester 2
- Determine useful parameters that describe data
- Train NN to differentiate between threats and false alarms

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

★ NN was programmed and tested with XOR problem
- 505 Epochs were needed to train data

★ FLC was added to NN and tested with XOR problem
- FLC controlled NN was much faster to train
- 19 Epochs were needed to train data

★ Data from AN/AAR-47 was acquired
- Data has been analyzed and has not been successfully trained with DSP techniques
- Data has been trained with R^2 techniques

New

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APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

Fuzzy Associative Memory (FAM) for Learning Rate

CCE \ CE	NB	NS	ZE	PS	PB
NB	NS	NS	NS	NS	NS
NS	NS	ZE	PS	ZE	NS
ZE	ZE	PS	PS	PS	ZE
PS	NS	ZE	PS	ZE	NS
PB	NS	NS	NS	NS	NS

NB - Negative Big
NS - Negative Small
ZE - Zero
PS - Positive Small
PB - Positive Big
CE - Change of Error
CCE - Change of CE

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

Fuzzy Associative Memory for Momentum

CCE \ CE	NB	NS	ZE	PS	PB
NB	NS	NS	ZE	ZE	ZE
NS	NS	ZE	ZE	ZE	ZE
ZE	ZE	PS	PS	PS	ZE
PS	ZE	ZE	ZE	ZE	NS
PB	ZE	ZE	ZE	NS	NS

CCE

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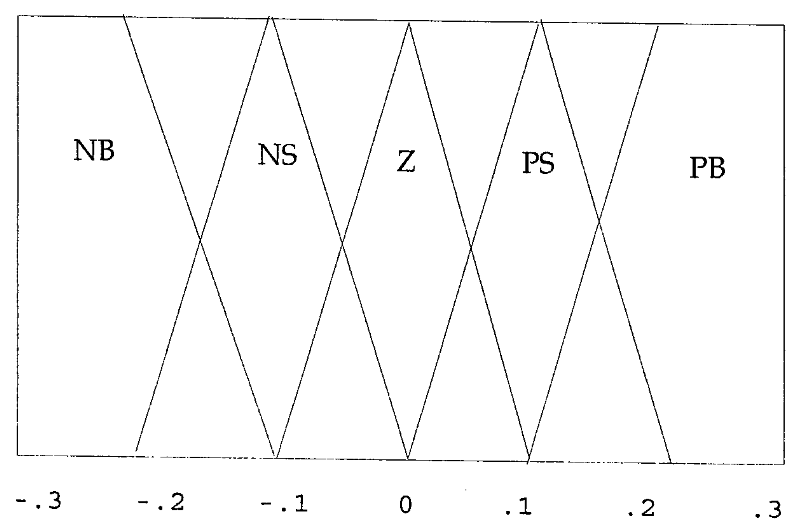
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

Input Variables CE and CCE



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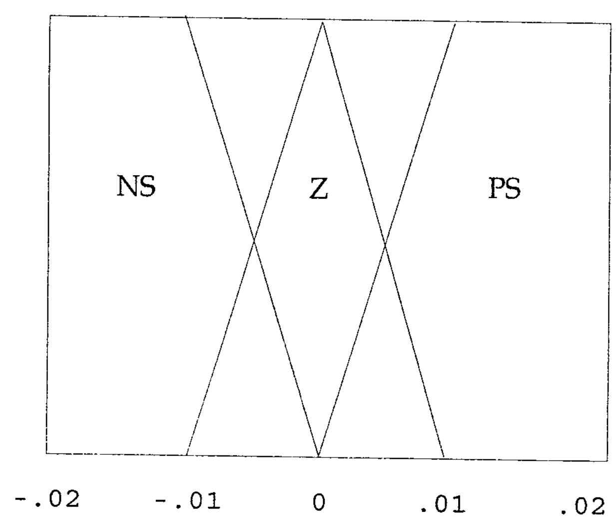
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

Output Variables Momentum and Learning Rate



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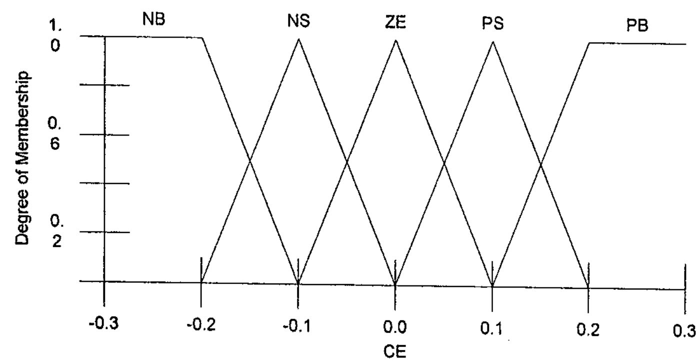
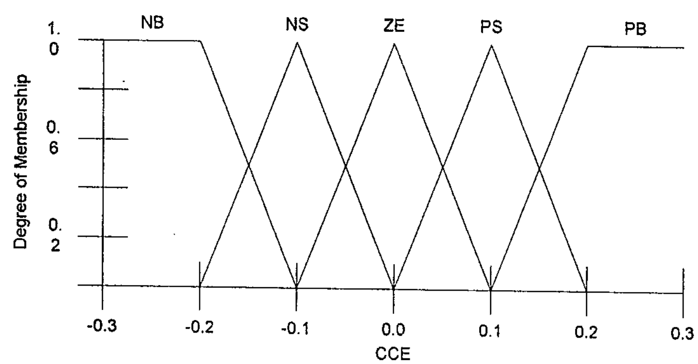
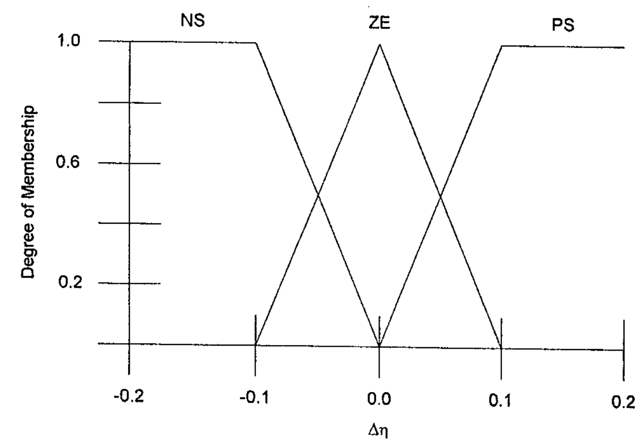
MODEL VARIABLES TO DETERMINE LEARNING RATE







ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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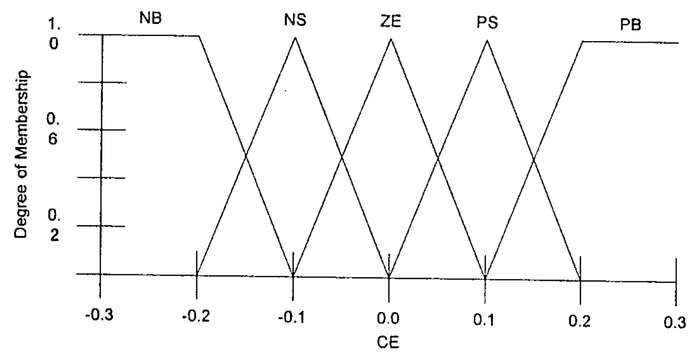
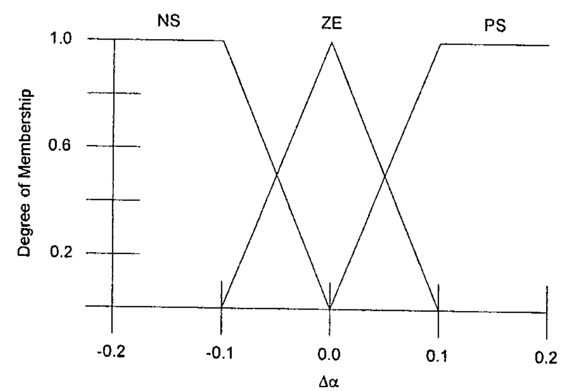
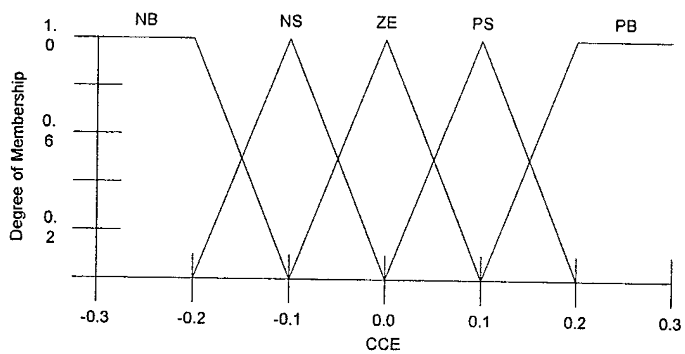
MODEL VARIABLES TO DETERMINE MOMENTUM







ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM
(RAPCEval)

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MS/SS Program
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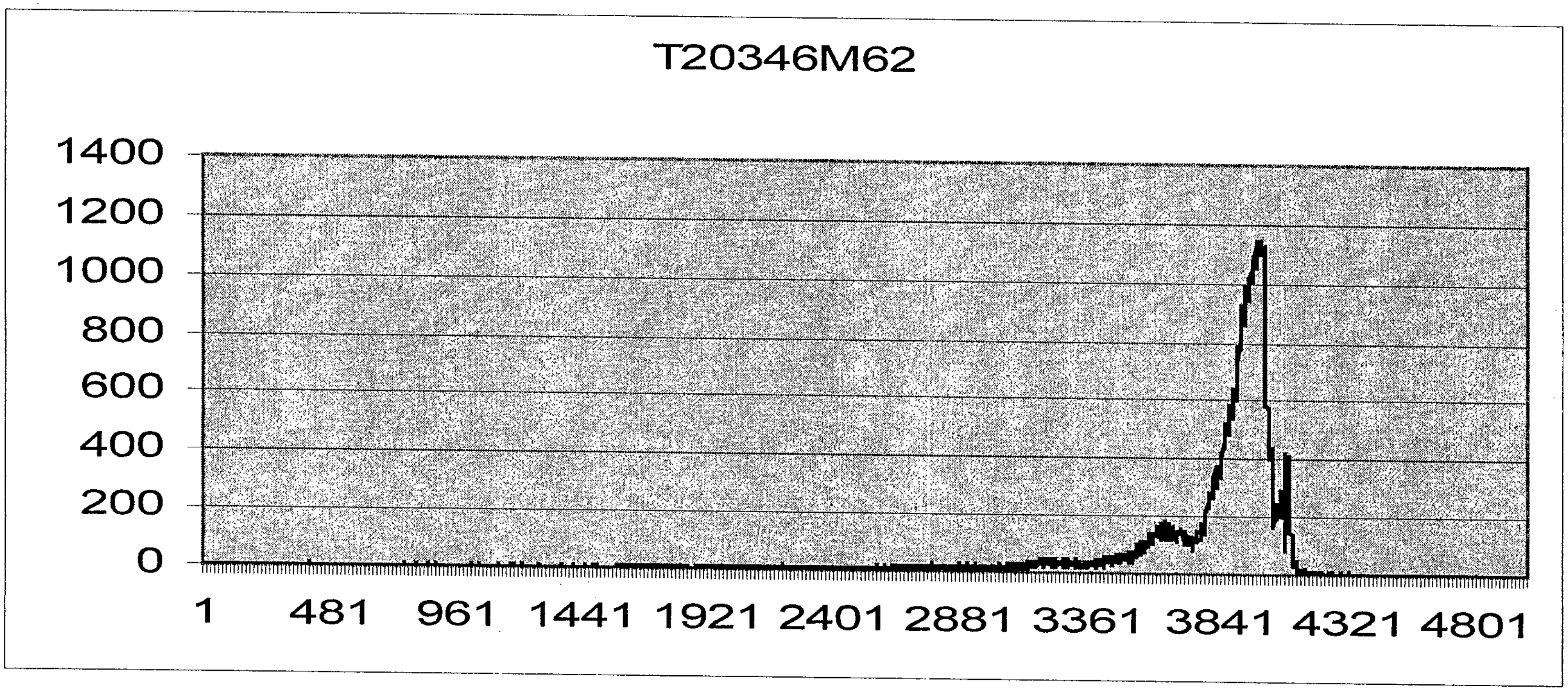
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT



ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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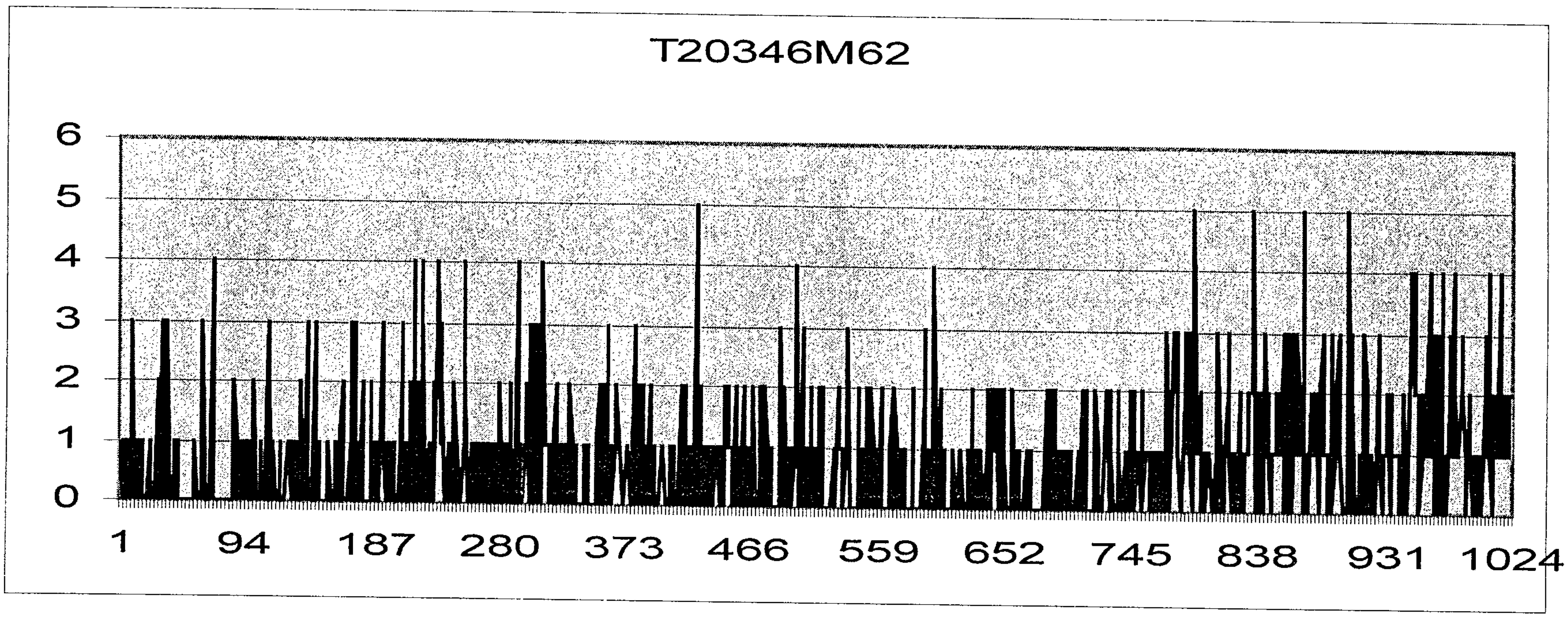
APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT



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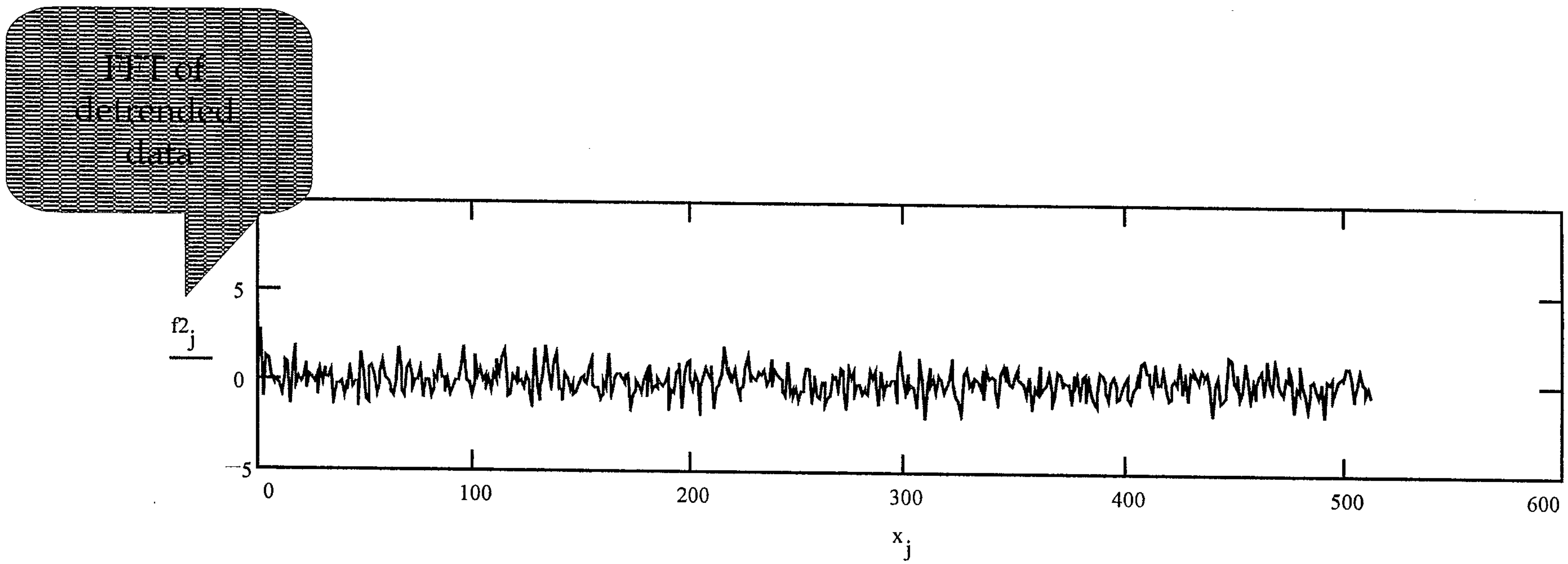
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT



ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

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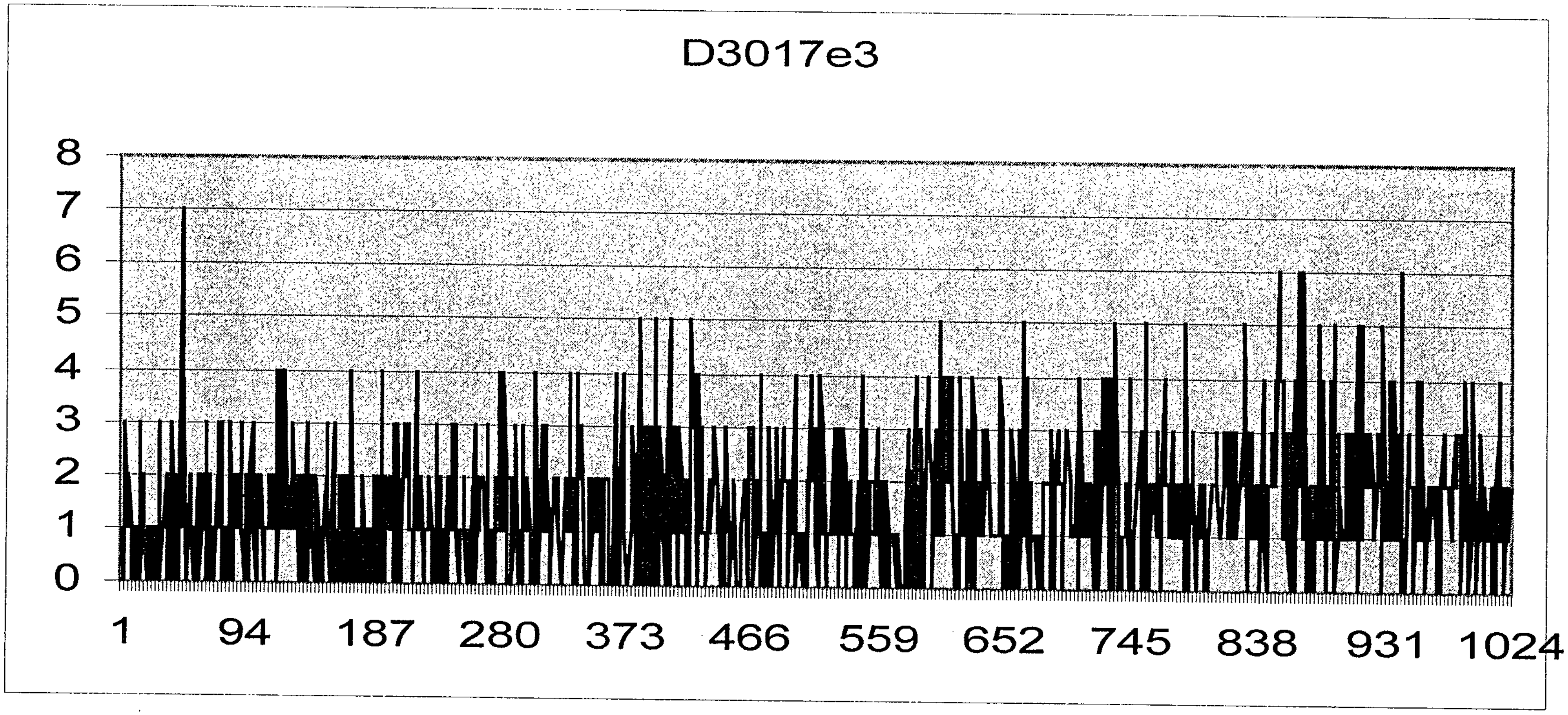
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT



ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

New

★ Final Parameters used to train Neural Network

- Measure of R^2 fitness
- Signal density or mean
- The X^2, X and constant coefficients for a polynomial least squares fit.

ELECTRONIC WARFARE CONCEPTS
EVALUATION PROGRAM
(RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

RESEARCH PROGRESS REPORT

New

★ Measure of R^2 fitness

- Find coefficients using polynomial least squares fit
  - $ans=(X^TX)^{-1}(X^TY)$
- Define function for fitness
  - $fit(q) = ans_2q^2+ans_1q+ans_0$
- $R^2 fitness = \Sigma(fit(x)-mean(v))^2/\Sigma\ (v-mean(v))^2$

ELECTRONIC WARFARE CONCEPTS EVALUATION PROGRAM (RAPCEval)

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

SUMMARY

New

- ★ Real Threats - 19
  - 9 detected before the minimal time
  - 3 detected after minimal time but close
  - 5 detected well under minimal time
  - 2 ignored as bad files
- ★ False Alarms - 24
  - 18 original false alarms passed as non signals
  - 6 signals produced a false alarm
    - all produced from jet aircraft signature

S. Boswell
MS/SS Program
RESEARCH

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

SUMMARY

★ Insufficient signal strength of threat at critical time before impact.

- Several threats are not much above background noise at this time.
- Lack of modulation prevented DSP techniques. New

★ False alarms exhibit R^2 characteristics and similar DSP characteristics to threats.

★ By combining R^2 characteristics with coefficient matrix input, was able to differentiate between threats and some false alarms. New

APPLICATION OF NEURAL NET WITH FUZZY LOGIC CONTROL TO AN/AAR-47 DATA

SUGGESTIONS FOR FURTHER WORK

★ Improve critical time value if possible so that more signal can be analyzed before classification.

★ Add Spectroscope capabilities to help in classification.

★ Find another parameter set for the input data that can help differentiate the F-18 from a real missile. New

- This may include changing the size of the matrices as well as adding new parameters.

★ Combine all four signals into the neural network. New

★ Improve on the matrix computations. New

5.3 Steering Committee, January 2000

5.3.1 Meeting Minutes

RF/Receiver and Processing Concepts Evaluation Program Program Research Standards Committee Meeting Minutes 6 January 2000

We had our first RAPCEVAL meeting via video teleconference this morning. The 16 attendees are listed in the attendance record. Nick Pequignot welcomed the group from the WPAFB site. Tom Bass presented his usual overview of the RAPCEval program.

Two students gave presentations of proposed research. The first, by Peter Bryant, a MERC employee, related to a novel approach to passive geolocation of microwave emitters. It included material MERC considers proprietary. The topic involves another fundamental variation on PLAID techniques. Current measurements versus theory comparisons make this technique appear very viable.

Bill Elliott made the other presentation. Its topic concerned ALQ-172 O-level testing of the V2 phased array antenna. The focus is on improving the false alarm and detection rates of that test by making selected measurements of the near field pattern using an improved antenna hat. The improvements will be made by sophisticated computer processing of the near-field collected data to emulate far-field measurement.

Ches Rehberg agreed that both projects appear promising, although it is always difficult to predict how much of a student's initial objectives can be achieved. Both of these projects should yield useful information, either proving or disproving the utility of new approaches to old problems. Ches commented that the air force is pleased to see new projects more closely tied to specific local EW needs.

The meeting closed with Nick's discussion of a soon coming delivery order to continue funding for the program. The next meeting is anticipated to be at Warner Robins on 30 March 2000.

Discussions:

All present generally appreciated the video-conferenced trial meeting. Some discussion of how to handle classified meetings ensued.

5.3.2 Meeting Agenda

Agenda

RAPCEval program

INTERIM STEERING COMMITTEE MEETING

2000 Jan 6 — 9:00 AM to 11:30 AM

Meeting will be via Tele-video conference between WPAFB & WRALC

WPAFB location: IFW Conference Room, 3rd floor of Building 620

WRALC location: meet at Steve Strawn's office, 3rd floor Building 226

WP Pictel #700-899-7050

WR Pictel # 700 899-2059

Meeting called by:	Nicholas Pequignot, AFRL/SNRP, AFRL Program Manager Steve Strawn, WR-ALC/LNERR, WRALC Program Manager	**Facilitator:** Dr. Tom Bass

	AF Research Laboratory	**Robins AFB**	**Mercer University**
Committee Members:	Mr Nicholas A Pequignot Mr Emil R Martinsek Mr Norman A Toto Dr Duane A Warner Mr Aaron P Linn	Mr Steve Strawn Mr John LaVecchia Mr Phil Oliver Mr Ches Rehberg Mr. Larry Sheets	Dr David Barwick Dr Tom Bass Dr Aaron Collins Dr Behnam Kamali Dr Paul MacNeil
Email addresses:	Nicholas.Pequignot@wpafb.af.mil Emil.Martinsek@wpafb.af.mil Norman.Toto@wpafb.af.mil Duane.Warner@wpafb.af.mil Aaron.Linn@wpafb.af.mil	Steve.Strawn@robins.af.mil John.Lavecchia@robins.af.mil Ches.Rehberg@robins.af.mil Larry.Sheets@robins.af.mil	dbarwick@merc.mercer.edu tbass@merc.mercer.edu collins_as@mercer.edu macneil_pe@mercer.peachnet.edu kamali_b@mercer.peachnet.edu

Schedule		
Setup & Verification of Pictel Links		0900
Welcome & Introductions	North – Nick Pequignot South – Tom Bass	0915-0930
RAPCEval Overview	Tom Bass	0930-0945
Student Proposals		
Rotary Doppler Technique for Passive Ranging (Has MERC Proprietary Markings)	Peter Bryant	0945-1015
A Modified Near-field Technique for Supporting a Phased Array Antenna System	Bill Elliott	1015-1045
Discussions & New Business	Tom Bass	1045-1130
Adjourn		1130

5.3.3 Attendance Roster

The attendees at this meeting are listed here:

RECORD OF ATTENDANCE - RAPCEval Video Conference 1/6/2000

#	First Name	Last Name	Company	Business Phone	E-mail Address
1	Tom	Bass	MERC	(912) 953-6800	bass_wt@mercer.edu
2	Joe	Black	MERC	(912) 953-6800	jblack@merc.mercer.edu
3	Pete	Bryant	MERC	(912) 953-6800	pbryant@merc.mercer.edu
4	Bob	Davis	AFRL/SNRP	(937) 255-6127x4323	Robert.Davis@sn.wpafb.af.mil
5	Bill	Elliott	WR-ALC/LYSTD	(912) 926-3359	bill.elliott1@robins.af.mil
6	Skip	Finnigan	MERC	(912) 953-6800	sfinnigan@merc.mercer.edu
7	James	Hedge	AFRL/SNRP	(937) 255-6127x4349	James.Hedge@sn.wpafb.af.mil
8	Jeng-Nan	Juang	Mercer University	(912) 301-2574	juang_jn@mercer.edu
9	Phil	Oliver	WR-ALC/LNERT	(912) 926-2588	phil.oliver@robins.af.mil
10	Clayton	Paul	Mercer University	(912) 301-2213	paul_cr@mercer.edu

11	Nicholas	Pequignot	AFRL/SNRP	(937) 255-6127x4235	Nicholas.Pequignot@sn.wpafb.af.mil
12	Ches	Rehberg	WR-ALC/LNEX	(912) 926-4525	ches.rehberg@robins.af.mil
13	Rudy	Shaw	MERC	(937) 431-8656	r.shaw@worldnet.att.net
14	Steve	Strawn	WR-ALC/LNERR	(912) 926-6435	steve.strawn@robins.af.mil
15	Duane	Warner	AFRL/SNJ	(937) 255-4174x4032	Duane.Warner@sn.wpafb.af.mil
16	Anthony	White	AFRL/SNRP	(937) 255-6127x4236	Anthony.White@sn.wpafb.af.mil

5.3.4 Overview of the Program (Dr. Bass)

The Overview Briefing of the RAPCEval Program as presented at this meeting is reproduced on the next 12 pages.

RAPCEval STEERING COMMITTEE MEETING

January 6, 2000

GENERAL PROGRAM INFORMATION

- ★Contract: F09603-93-G-0012-0017
- ★Customer: Air Force Research Laboratory, Sensors Division (AFRL/SN)
- ★Contract Value: $349,964

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

January 2000

PROGRAM STATUS

- ★ Graduate Research Jointly Supported by Mercer, AFRL, WR-ALC, and Industry
- ★ Thirteen successful research projects (with Masters' degrees) have been completed
- ★ Six ongoing research projects

PROGRAM STATUS

- ★ Research has been approved by the steering committee to be useful to the Air Force
- ★ Research has been found to have academic merit by the university and by the committee

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

January 2000

PROGRAM RESEARCH STANDARDS COMMITTEE MEMBERS

★ *AF RESEARCH LAB*

Nick Pequignot (PM)
Aaron Linn
Emil R. Martinsek
Norman A. Toto
Duane A. Warner

★ *MERCER UNIVERSITY*

Aaron Collins
Benham Kamali
Paul MacNeil

★ *WR-ALC*

Steve Strawn (PM)
John LaVecchia
Phil Oliver
Ches Rehburg
Larry Sheets

★ *MERC*

David Barwick (Chmn)
Tom Bass (PM)

GRADUATES & REPORT REFERENCES

- ★ *Mark Astin,* "Application of Parallel Computing Techniques to the RAD Algorithm", (classified) AFRL-SN-WP-TR-1998-1088
- ★ *Henderson Benjamin,* "Selection of Reed Solomon Codes Using Neural Networks", AFRL-SN-WP-TR-1998-1056, p. 131
- ★ *Ron Brinkley,* "Burst Error Correction with Reed-Solomon Codes", AFRL-SN-WP-TR-1999-1115, p. 254

GRADUATES & REPORT REFERENCES

- ★ *Mark Campbell,* "Auto-Regressive Spectral Analysis - EW Applications", WL-TR-94-1057
- ★ *Randy Ford,* "Passive Location via Evolutionary Genetic Algorithms", forthcoming report, Spring 2000
- ★ *Claus Franzkowiak,* "Four-Pulse Primary RAD Filter Development", (classified) AFRL-SN-WP-TR-1998-1087

GRADUATES & REPORT REFERENCES

- ★ *Neal Garner*, "Error Correction and Prediction for Improved Communication of Time and Time Measurements", WL-TR-96-1161
- ★ *Joseph Kelley* , " A Parameter Determination Alternative for RAD Analysis", (classified) WL-TR-95-1005
- ★ *Joseph Kelley*, "MultiGroup Simultaneous RAD Parameter Selection", (classified) WL-TR-97-1094

GRADUATES & REPORT REFERENCES

- ★ *Max Roesel,* "Agile RF/PRI Radar Analysis via RAD", (classified) WL-TR-95-1020
- ★ *Dave Schuler,* "Comparison of Algorithms for Geolocation of Radar Signals", WL-TR-96-1161
- ★ *Tracy Tillman,* "Hardware Implementation for an Advanced Pulse Processing Algorithm", (classified), AFRL-SN-WP-TR-1998-1085

GRADUATES & REPORT REFERENCES

★ *Kirk Wright*, "Object Oriented Modeling of the AN/ALQ-172", (classified) AFRL-SN-WP-TR-1998-1086

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM
(RAPCEval) OVERVIEW

January 2000

TODAY'S STUDENT PRESENTATIONS

★ *Peter Bryant,* "Passive Geolocation using Rotational Doppler Induced by the Angular Velocity Imposed upon an Antenna Baseline"

★ *Bill Elliott,* "A Modified Near-field Technique for Supporting a Phased Array Antenna System"

ONGOING & PLANNED STUDENT RESEARCH

- ★ *Peter Bryant* – Rotational Doppler
- ★ *Bill Elliott* – Near-field Phase-Array Antenna
- ★ *Kerwin Holmes* - GPS Enhancement
- ★ *Houston Jones* – CDMA System Error Coding
- ★ *Mark Napier* - IFF Improvement
- ★ *Wes Stinehelfer* - GPS Wavelet Processing

5.3.5 Presentation by Bill Elliott

The student briefing presented by Bill Elliott at this meeting is reproduced on the next 17 pages.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

RESEARCH PROPOSAL PRESENTATION

Richard W. Elliott, Jr.

WR-ALC/LYSTD
Robins AFB, GA

Background and Experience:

Education:	BSEE from University of Mississippi
	Pursuing MSEE - 24.66 hrs. completed
LYSTD:	AN/ALQ-172 Avionics Test Engineer

Research Topic:

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING A PHASED ARRAY ANTENNA SYSTEM

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROBLEM STATEMENT

We are not detecting many Phased Array Antenna System (PAAS) faults in the field due to the limited testing capability available in the field.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROPOSAL JUSTIFICATION

- ★ Applicability to Mercer University MSEE Program
  - Different approach to antenna testing.
  - Require investigation in area outside normal program of study.
- ★ Applicability to the USAF
  - Better testing will result in more efficient system.
  - Better field test will result in lower depot cost and turnaround time.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROPOSED RESEARCH OBJECTIVES

★ The AN/ALQ- 172 field test can be improved.

- Establish computer requirements.
- Establish RFIU modification requirements.

★ Provide an alternate field test ideas for other systems.

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROPOSED METHOD OF INVESTIGATION

★ NEC-4 Software Modeling of the Antenna
- Far-field Verification on tester
- Modified Near-field Estimates

★ Measure Good and Bad Antenna Patterns
- Build a Test Jig
- Verify Near-field Estimates.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROPOSED SCHEDULE

- ★ Semester 1 (Spring 2000)
  - Construct PAAS Software Model
  - Analyze PAAS Model
  - Start Construct of Test Jig
- ★ Semester 2 (Summer 2000)
  - Finish Construct of Test Jig
  - Start Building PAAS Test Database

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROPOSED SCHEDULE

★ Semester 3 (Fall 2000)

- Finish Building PAAS Test Database
- Analyze and Make Recommendations
- Write and Submit Thesis

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

★ Conventional near field measurements are made by physically moving the sensing antenna, in a precise path along the front of the antenna.

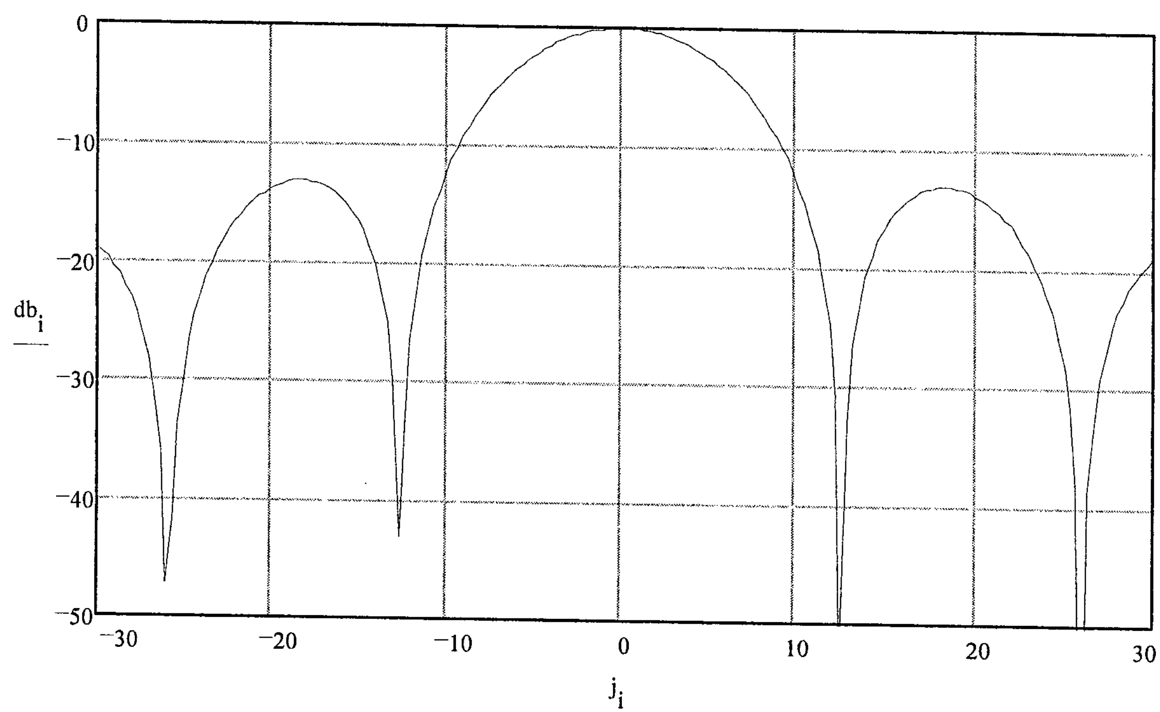
★ Instead of physically moving the sensing antenna, it will be moved electronically, by varying the wavelength, in small steps.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

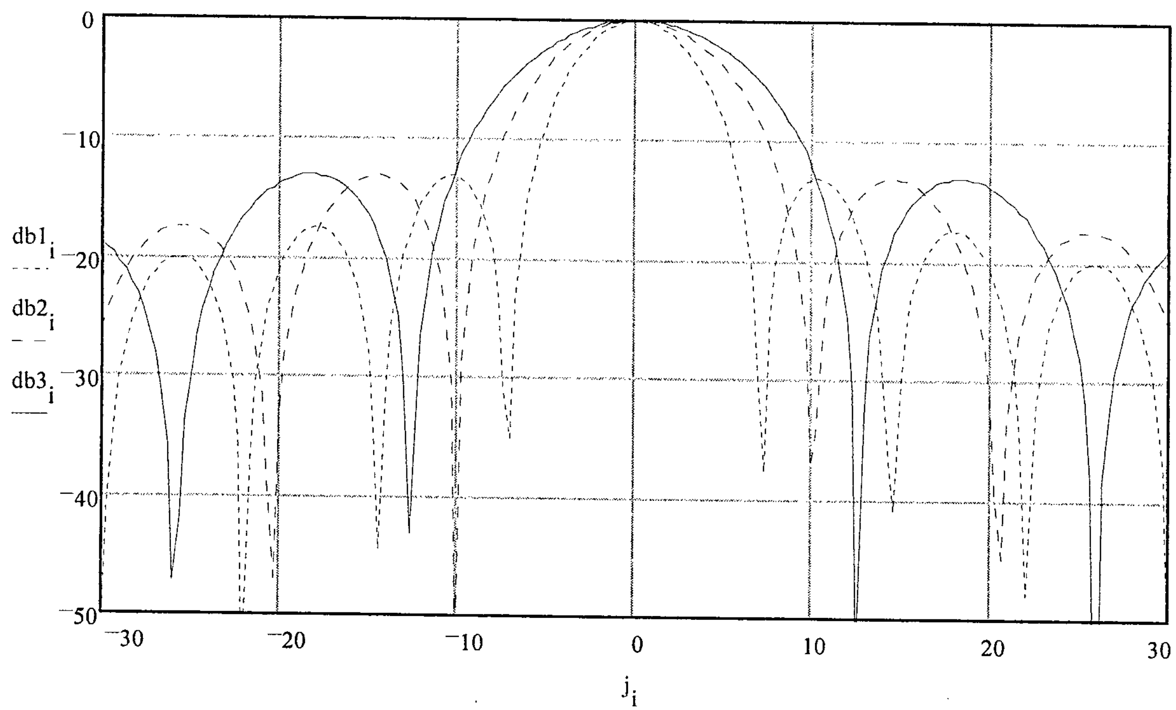


RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION



RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

★ The NEC software will be used to determine

- Minimum step resolution needed for reasonable accuracy.
- Minimum number of sensing antennas required for an accurate model.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

★ The test jig is preferable to using a RFIU
- Ease and cost of modifying the jig.
- Pedestal would have to be modified.

★ This test jig would be constructed in a manner, so it could be removed for normal ARTF testing.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

★ Expected Results
- The field test can be improved.
  - Some limitations in the field test will remain.
- The field tester computer is too limited.
  - The computer can be upgraded for minimal cost.

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

★ Hardware Requirements

- Test Jig
    - Many fabrication parts can be borrowed from spares.
    - Cost impact should be minimal.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

TECHNICAL PRESENTATION

★ Software Requirements

- NEC-4
  - Received in 8 Dec 1999.
- GNEC
  - Total Cost $840.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

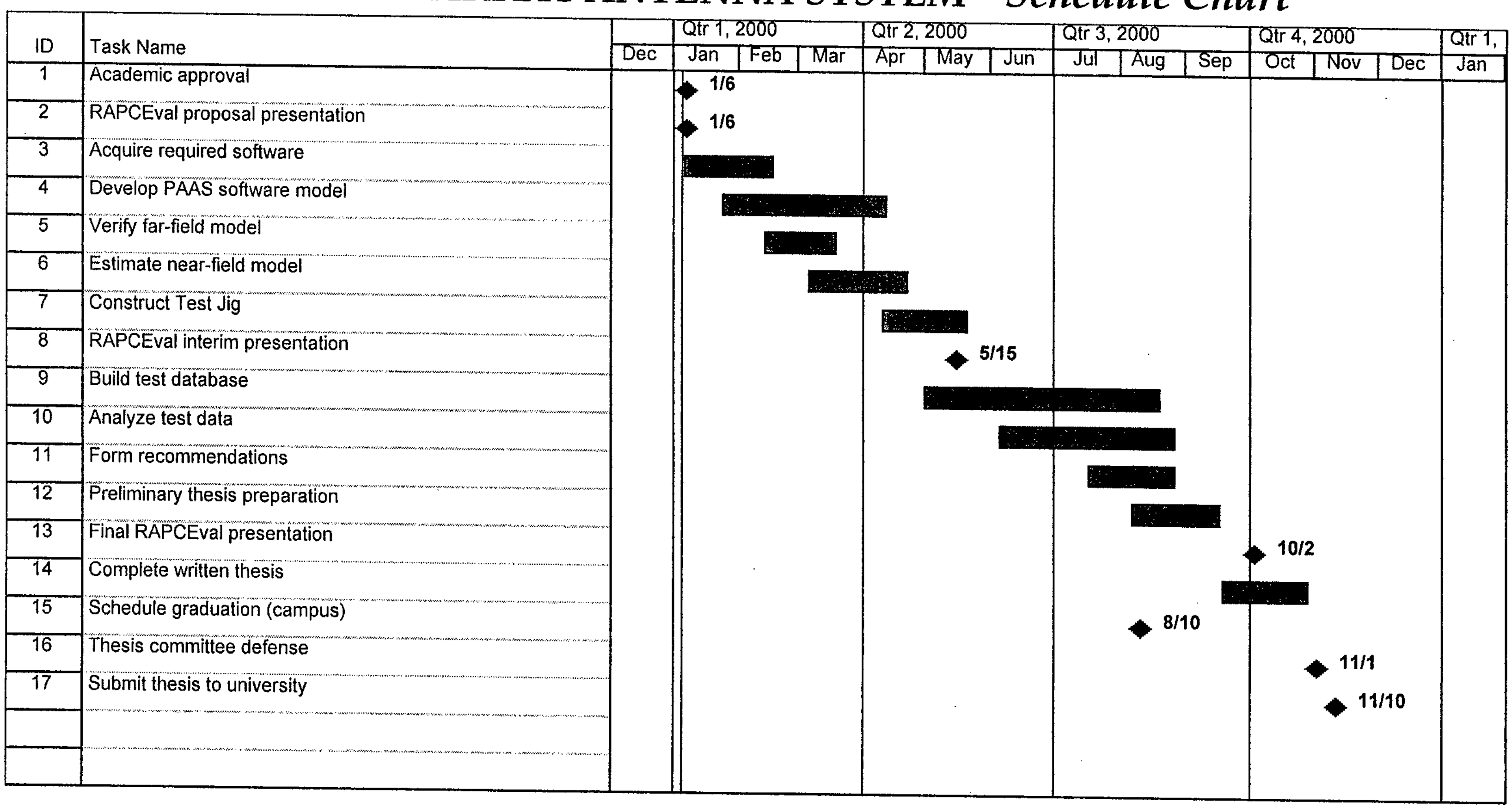
TECHNICAL PRESENTATION

★ Training Requirements
- NEC / GNEC Tutorial
- Near-field measurement

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
PROPOSAL
01/06/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM - Schedule Chart



5.4 Steering Committee, March 2000

5.4.1 Meeting Minutes

RF/Receiver and Processing Concepts Evaluation Program
Program Research Standards Committee Meeting Minutes
30 March 2000

The RAPCEval Steering Committee Meeting met at Mercer Engineering Research Center on March 30, 2000. There were 13 members and students present at the meeting.

After a brief time of refreshments, Dr. David Barwick welcomed everyone to open the meeting.

Following the welcome, Dr. Tom Bass presented an overview of the programs finances and contractual details. He then discussed accomplishments of the RAPCEval program, outlining the list of graduates and their thesis topics, as well as references to each student's publication. During the overview, Mr. Nick Pequignot discussed various contract vehicles available for future funding. He also inquired about the latest financial information on the program. Some discussion focused on membership of the committee. There is a priority on reducing the rank of committee members, in an attempt to allow improved attendance at the steering meetings. Also, Mr. Phil Oliver pointed out that one of the WR-ALC members, Mr. John LaVecchia, would need replacement, since his retirement will occur soon.

Dr. Bass then continued the meeting by introducing the talks by the students. Dr. Bass pointed out that the MERC-proprietary talk to be given by Mr. Pete Bryant did not involve work funded by RAPCEval, but the talk was of great interest to the RAPCEval participants, so the program was funding only Peter's presentation costs.

The students now gave their presentations. The first talk was given by Mr. Peter Bryant. Peter's topic relates to the Precision Location and Identification (PLAID) program that has been contracted by MERC with the AFRL (Dayton). During PLAID activities, a novel approach to passive emitter location was discovered by Mr. Skip Finnigan of MERC, involving dynamic RF phase changes induced in receivers during flight. Peter has been researching the possibilities of the effect, and MERC has applied for a patent on the process. Peter's talk detailed the algorithms designed to exploit the effect.

Following Peter was a talk by Mr. Bill Elliott. Bill has been using numerical electromagnetic code (NEC) and trade name for version of NEC (GNEC) software to design tests that might be useful in finding defects in the field in phased array antennas. Typically, a hat is placed over antennas during field test. The hat gathers data that is unfortunately measured in near field. This test often misses defects that are later discovered after antenna removal and shipment to the service depot, where far field tests are utilized. Bill's contribution is algorithmic improvements for the hat test that potentially allow emulated far-field measurements despite the close proximity of the test box.

The final talk was presented by Mr. Mark Napier. Mark discussed potential robustivity measurements for IFF signals by use of Reed Solomon corrective codes. Mark has discovered from experts in the field that even though the IFF signals are usually not corrupted in ideal one-

on-one environments, there are problems with overlapping signals from multiple aircraft obscuring one another. He has presented solutions to this problem and is designing a firmware solution for an field programmable gate array (FPGA) implementation.

5.4.2 Agenda

RAPCEval Steering Committee Meeting
March 30, 2000 - 9:00 to 11:45 A.M.

Mercer Engineering Research Center
135 Osigian Boulevard
Warner Robins, Georgia 31088
voice (912)-953-6800 fax (912)-953-6807

Renew Acquaintances; Refreshments		9:00 - 9:10
Welcome & Introductions	Dave Barwick	9:10...
RAPCEval Overview	Tom Bass	...9:25
Student Presentations		
Rotary Doppler Technique for Passive Ranging (has MERC Proprietary Markings)	Peter Bryant	9:25 - 9:50
Wavelet Algorithm as a Substitute for Fourier Algorithm in Software GPS Analysis	Wes Stinehelfer	9:50 - 10:15
A Modified Near-field Technique for Supporting a Phased Array Antenna System	Bill Elliott	10:15 - 10:40
Civil IFF Reed-Solomon Code Application	Mark Napier	10:40 - 11:05
Discussions & New Business	Tom Bass	11:05 - 11:45
Adjourn		11:45

5.4.3 Attendance Roster

The attendees at this meeting are listed here:

ID	Name	Organization	Phone	Email Address
1	Tom Bass	MERC	912-953-6800	bass_wt@mercer.edu
2	RP (Phil) Oliver	WR-ALC/LNERT	912-926-2588	phil.oliver@robins.af.mil
3	Mark Napier	Scientific Atlanta	770-903-6980	mark.napier@sciatl.com
4	Nicholas Pequignot	AFRL/SNRP	937-255-6127, x4235	nicholas.pequignot@wpafb.af.mil
5	Ches Rehberg	WR-ALC/LNEX	912-936-4525	ches.rehberg@robins.af.mil
6	Jack Tehan	MERC	941-575-4867	jtehan@insi.net
7	Dave Barwick	MERC	912-953-6800	dbarwick@merc.mercer.edu
8	Bill Elliott	WR-ALC/LYSTD	912-923-3359	bill.elliott1@robins.af.mil
9	James Hedge	AFRL/SNRP	937-255-6127, x4346	james.hedge@wpafb.af.mil
10	Skip Finnigan	MERC	912-953-6800	sfinnigan@merc.mercer.edu
11	Peter Bryant	MERC	912-953-6800, x2408	pbryant@merc.mercer.edu
12	Behnam Kamali	Mercer	912-752-2415	kamali_b@mercer.edu
13	Charles Bass	MERC	912-953-6800	cbass@merc.mercer.edu

5.4.4 Overview of the Program (Dr. Bass)

The Overview Briefing of the RAPCEval Program as presented at this meeting is reproduced on the next 13 pages.

RAPCEval STEERING COMMITTEE MEETING

March 30, 2000

GENERAL PROGRAM INFORMATION

- ★ Contract:
  F09603-93-G-0012-0017
- ★ Customer:
  Air Force Research Laboratory, Sensors Division (AFRL/SN)
- ★ Contract Value:
  $349,964

PROGRAM STATUS

- ★ Graduate Research Joint Support:
  by Mercer University, Air Force Research Lab (Dayton), Warner Robins Air Logistics Center and various industry contributors
- ★ Successful research projects:
  completion by 13 masters' degree candidates
- ★ Ongoing research:
  projects underway by 6 current graduate students

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

March 2000

PROGRAM STATUS

- ★ RAPCEval Research is *Useful*:
  all research is approved by the project steering committee to be of value to the Air Force
- ★ RAPCEval Research is *Academically Credentialed*:
  the university and by the student's graduate committee approves the research

PROGRAM RESEARCH STANDARDS COMMITTEE MEMBERS

★ *AF RESEARCH LAB*
Nick Pequignot (PM)
Aaron Linn
Emil R. Martinsek
Norman A. Toto
Duane A. Warner

★ *MERCER UNIVERSITY*
Aaron Collins
Benham Kamali
Paul MacNeil

★ *WR-ALC*
Steve Strawn (PM)
John LaVecchia
Phil Oliver
Ches Rehburg
Larry Sheets

★ *MERC*
David Barwick (Chmn)
Tom Bass (PM)

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

March 2000

GRADUATES & REPORT REFERENCES

- ★ *Mark Astin,* "Application of Parallel Computing Techniques to the RAD Algorithm", (classified) AFRL-SN-WP-TR-1998-1088
- ★ *Henderson Benjamin,* "Selection of Reed Solomon Codes Using Neural Networks", AFRL-SN-WP-TR-1998-1056, p. 131
- ★ *Ron Brinkley,* "Burst Error Correction with Reed-Solomon Codes", AFRL-SN-WP-TR-1999-1115, p. 254

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- ★ *Mark Campbell,* "Auto-Regressive Spectral Analysis - EW Applications", WL-TR-94-1057
- ★ *Randy Ford,* "Passive Location via Evolutionary Genetic Algorithms", forthcoming report, Spring 2000
- ★ *Claus Franzkowiak,* "Four-Pulse Primary RAD Filter Development", (classified) AFRL-SN-WP-TR-1998-1087

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- ★ *Neal Garner*, "Error Correction and Prediction for Improved Communication of Time and Time Measurements", WL-TR-96-1161
- ★ *Joseph Kelley* , " A Parameter Determination Alternative for RAD Analysis", (classified) WL-TR-95-1005
- ★ *Joseph Kelley*, "MultiGroup Simultaneous RAD Parameter Selection", (classified) WL-TR-97-1094

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- ★ *Max Roesel*, "Agile RF/PRI Radar Analysis via RAD", (classified) WL-TR-95-1020
- ★ *Dave Schuler*, "Comparison of Algorithms for Geolocation of Radar Signals", WL-TR-96-1161
- ★ *Tracy Tillman*, "Hardware Implementation for an Advanced Pulse Processing Algorithm", (classified), AFRL-SN-WP-TR-1998-1085

GRADUATES & REPORT REFERENCES

- ★ *Kirk Wright*, "Object Oriented Modeling of the AN/ALQ-172", (classified) AFRL-SN-WP-TR-1998-1086

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

March 2000

TODAY'S STUDENT PRESENTATIONS

- ★ *Peter Bryant,* "Passive Geolocation using Rotational Doppler Induced by the Angular Velocity Imposed upon an Antenna Baseline"
- ★ *Bill Elliott,* "A Modified Near-field Technique for Supporting a Phased Array Antenna System"

TODAY'S STUDENT PRESENTATIONS

- ★ *Houston Jones,* "Evaluation of Reed-Solomon codes for CDMA systems"
- ★ *Mark Napier,* "Application of Reed-Solomon Codes to Improve Noise Resistance of Civil IFF Communication"

EW RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval) OVERVIEW

March 2000

ONGOING & PLANNED STUDENT RESEARCH

- ★ *Peter Bryant* – Rotational Doppler
- ★ *Bill Elliott* – Near-field Phase-Array Antenna
- ★ *Kerwin Holmes* - GPS Enhancement
- ★ *Houston Jones* – CDMA System Error Coding
- ★ *Mark Napier* - IFF Improvement
- ★ *Wes Stinehelfer* - GPS Wavelet Processing

5.4.5 Presentation by Bill Elliott

The student briefing presented by Bill Elliott at this meeting is reproduced on the next 10 pages.

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

Richard W. Elliott, Jr.

WR-ALC/LYSTD
Robins AFB, GA

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
STATUS
03/30/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROBLEM STATEMENT

We are not detecting many Phased Array Antenna System (PAAS) faults in the field due to the limited testing capability available in the field.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
STATUS
03/30/2000

A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

PROPOSED METHOD OF INVESTIGATION

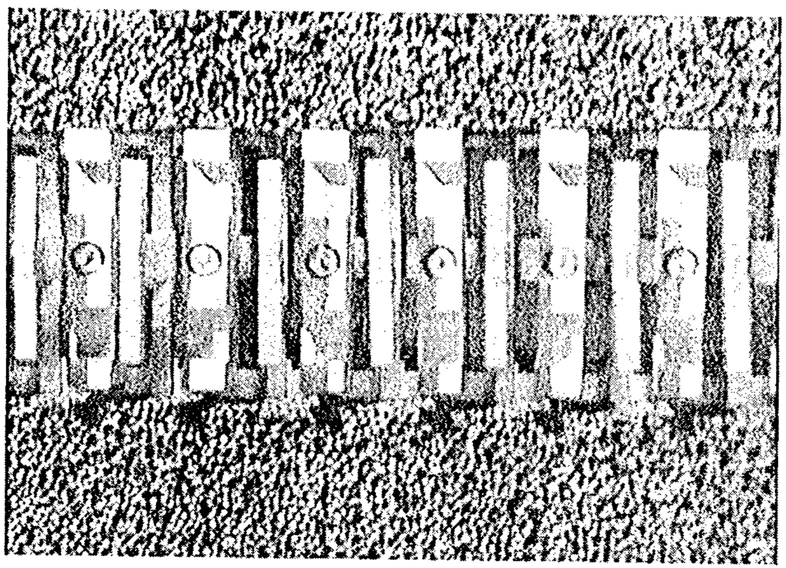
★ NEC-4 Software Modeling of the Antenna
- Far-field Verification on tester
- Modified Near-field Estimates

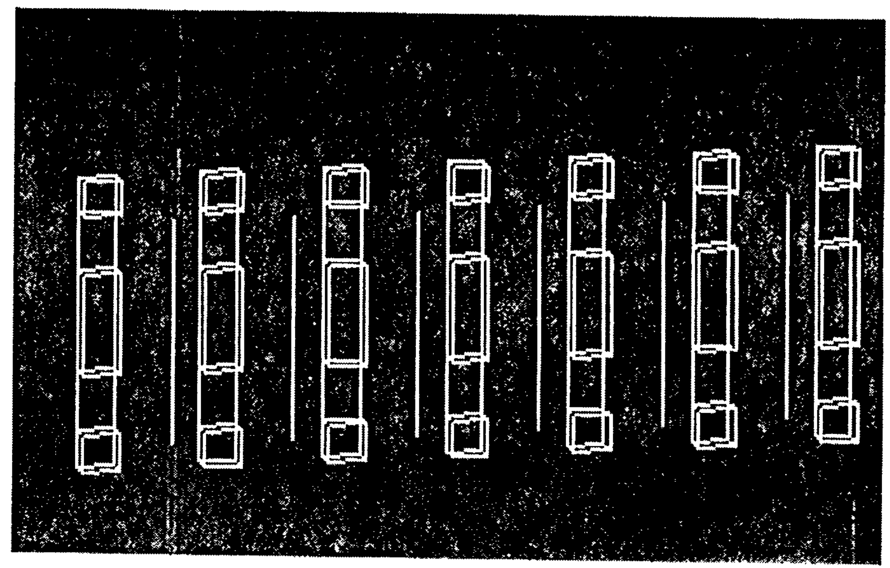
★ Measure Good and Bad Antenna Patterns
- Build a Test Jig
- Verify Near-field Estimates.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
STATUS
03/30/2000

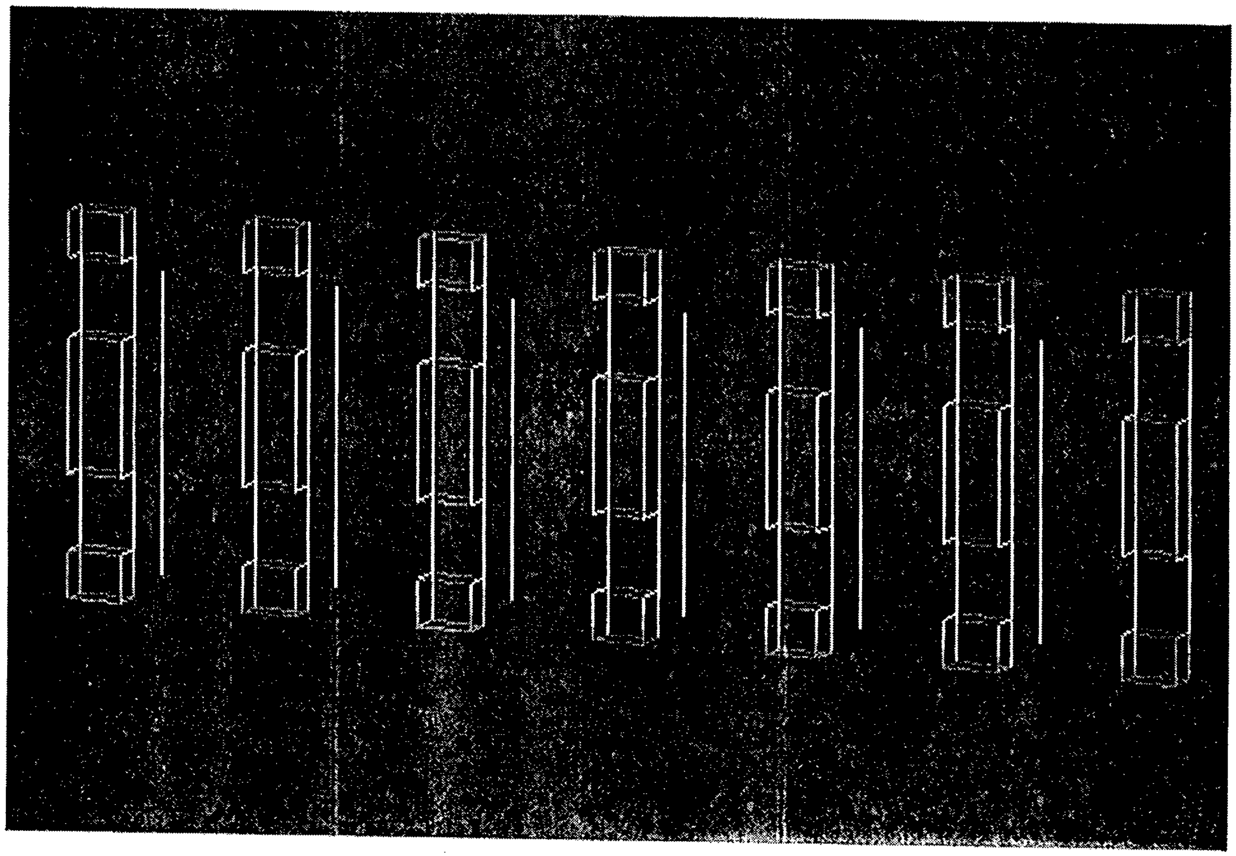
Antenna Elements and NEC Model





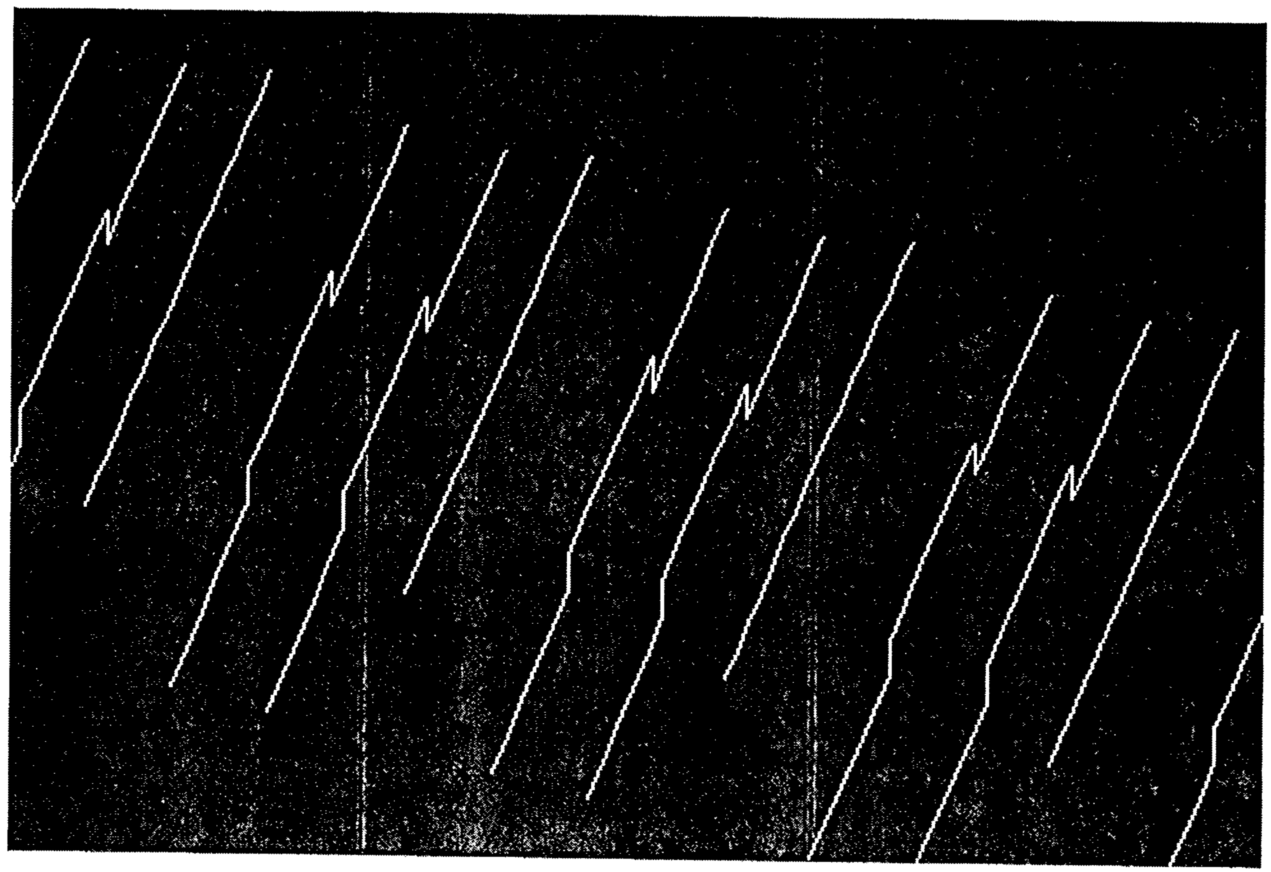
R. Elliott
STATUS
03/30/2000

Analyze Antenna Currents



R. Elliott
STATUS
03/30/2000

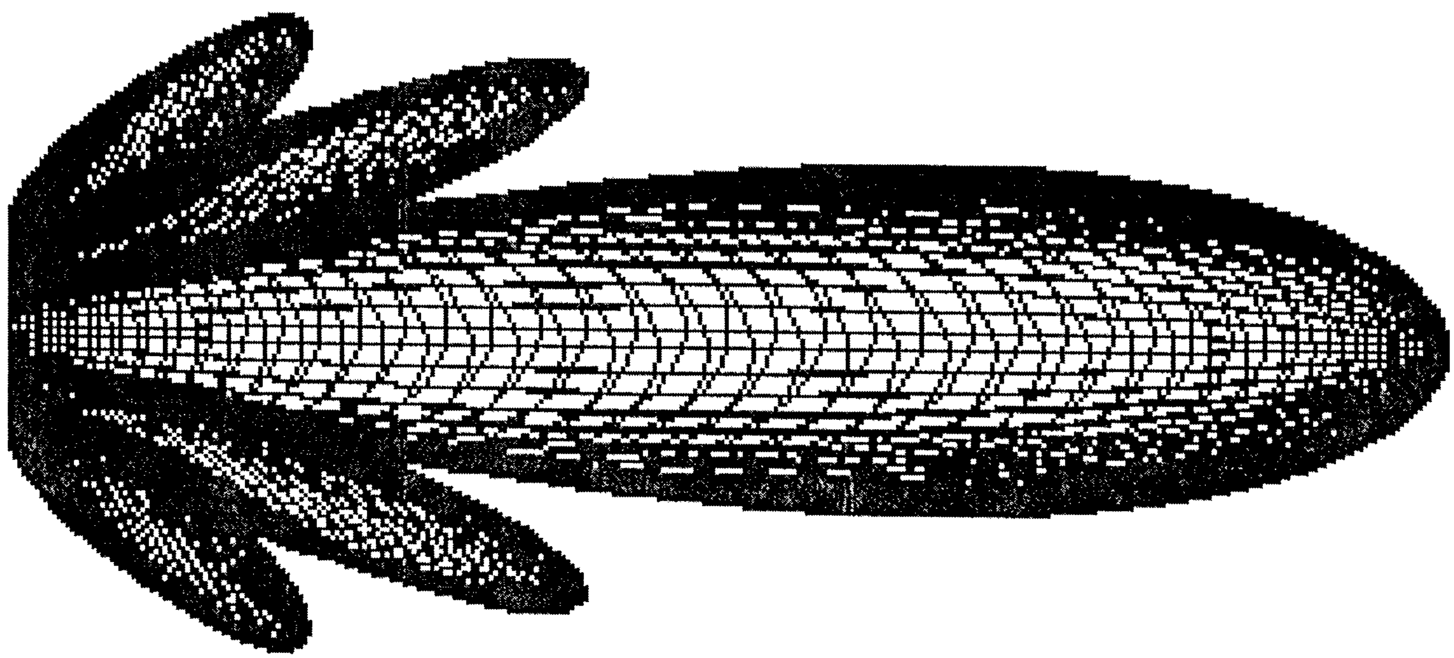
Final Working NEC Model



RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
STATUS
03/30/2000

NEC Antenna Pattern



RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
STATUS
03/30/2000

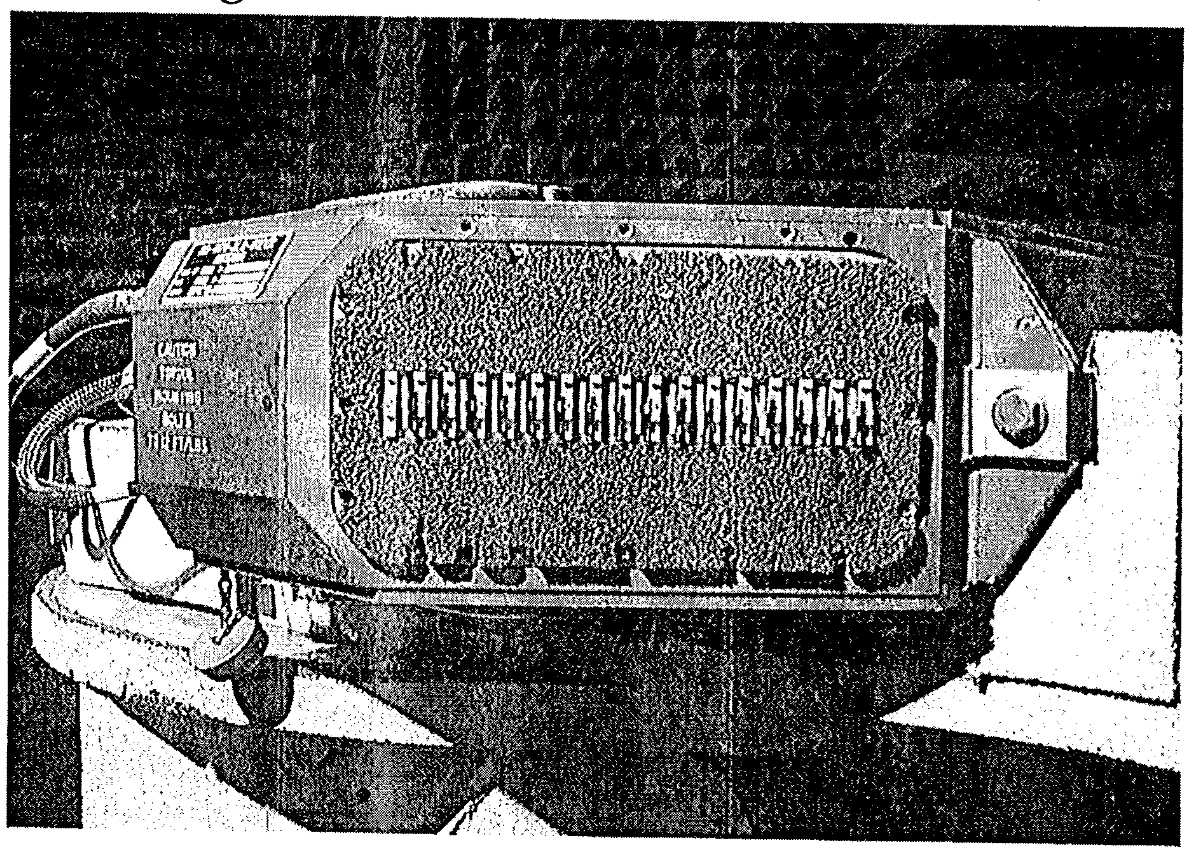
A MODIFIED NEAR-FIELD TECHNIQUE FOR SUPPORTING THE PHASED ARRAY ANTENNA SYSTEM

FAR-FIELD VERIFICATION RESULTS

★ Side Lobe Level (Left only)
- Tester is -13.35 dB down from peak
- NEC is -13.38 dB down from peak

★ NEC Null Angle within 0.5° of Tester

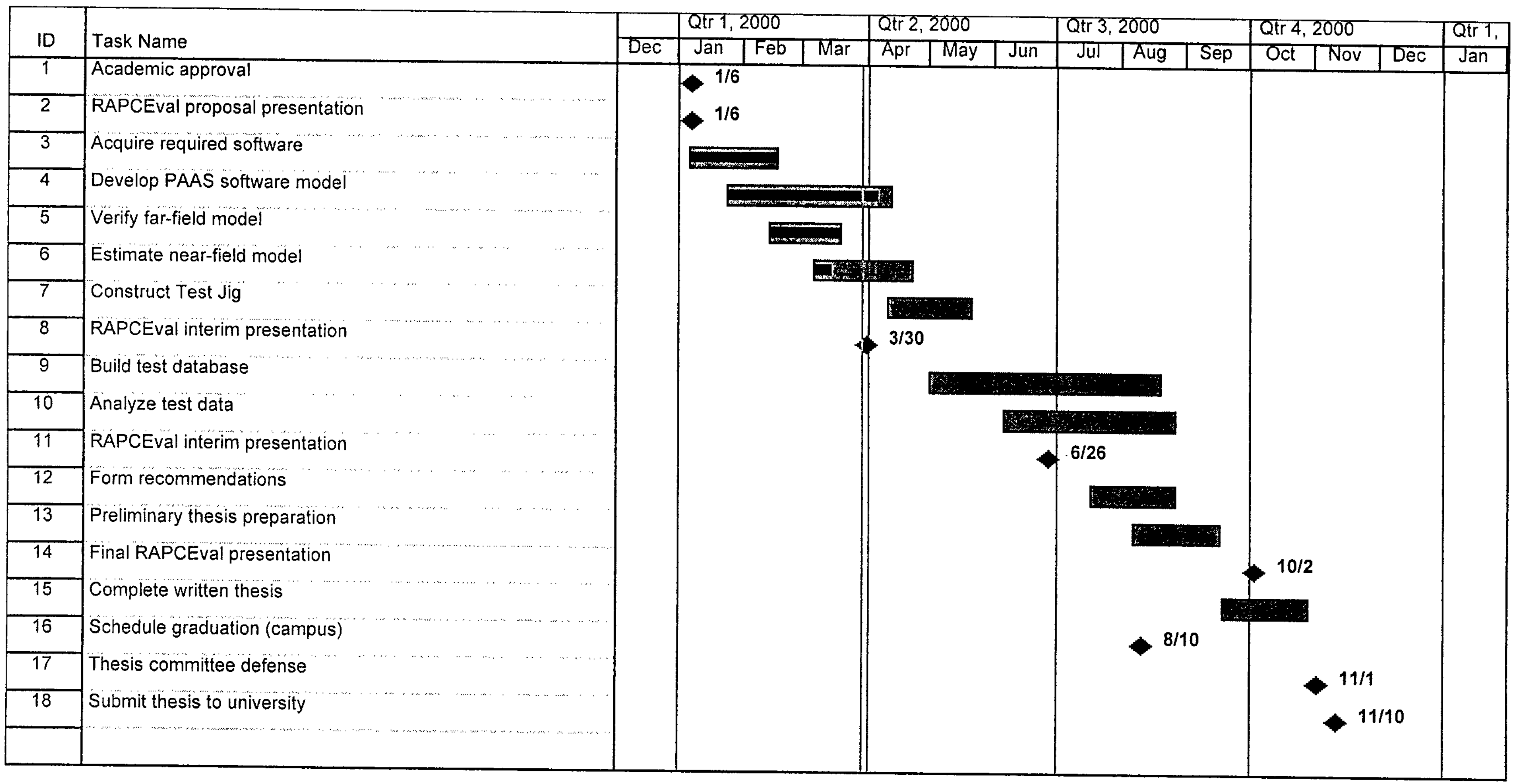
Right Lobe Antenna Test Problem



RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

R. Elliott
STATUS
03/30/2000

Schedule



5.4.6 Presentation by Mark Napier

The student briefing presented by Mark Napier at this meeting is reproduced on the next 18 pages.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

RESEARCH PRESENTATION

David M. Napier

Scientific Atlanta
ASIC Engineer, Digital Subscriber Group

Background and Experience:

Education: BSCPE from North Carolina State University.
Pursuing MSEE with emphasis in Digital Communications - 32 Semester hrs. completed.

Scientific Atlanta:
Digital and Analog Electronics Design, ASIC design and test.

Research Topic:
APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROBLEM STATEMENT

A proposed aircraft collision avoidance scheme uses the existing civilian IFF system. The technique uses the Mode S signaling scheme but defines a new message. The GPS position and velocity along with barometric altitude are transmitted instead of aircraft ID.

The new message is 112 bits long, 40 of which have been reserved for FEC coding. The proposed FEC scheme is a 5 bit t=4 Reed-Solomon code, RS(31,23). The proposed work is to analyze this scheme to determine the reliability improvements to be realized from the RS code. A decoder will be designed, implemented and tested in Verilog.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROJECT JUSTIFICATION

★ Applicability to Mercer University MSEE Program
- Digital Communication Classes Provide Material
- RS Decoder Engine useful for other projects

★ Applicability to the USAF
- Similar encoding could be used in Military IFF
- Military aircraft could participate in the civilian system without revealing aircraft ID

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

RESEARCH OBJECTIVES

- ★ Model the Mode S Modulation Scheme with RS
  - Verify that the Model Agrees with Analytical Predictions
  - Show that System Performance is Increased
- ★ Design the RS Decoder
  - Design the Decoder in Verilog
  - Verify with Verilog Testbench

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

METHOD OF INVESTIGATION

- ★ Implement RS Decoder in Verilog
- ★ Model the IFF Mode S Modulation Scheme
  - Literature Search and Analysis
  - Model Development and Verification
- ★ Model the System with RS FEC coding
  - Model without Erasure Information
  - Model with Erasure Information

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

PROPOSED SCHEDULE

★ Summer Semester

- Finalize analysis as a basis for model.
- Develop and verify PPM model.
- Simulate in presence of noise and interfering signals with RS coding.
- Finish testing decoder for RS(31,23) code.
- Document results and submit project report.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

TECHNICAL PRESENTATION

The civilian aircraft transponders are based on a WWII IFF (Information Friend or Foe) system. It is intended for ground based ATCRBS (Air Traffic Control Radar Beacon System) use and in general no information is available to aircraft not using air traffic control services. TCAS provides major air carriers with collision avoidance information but is an expensive system that has very limited capacity. A distributed collision avoidance system using GPS(Global Positioning System) would be inexpensive and highly reliable.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

The current system interrogates aircraft on 1030 MHz. The transponders respond on 1090MHz with mode 3A (squawk code), mode C (squawk altitude), or various mode S (squawk ID) messages depending on the interrogation sequence received and the transponder's capability. It transmits at a peak power output of 250 Watts. It uses pulse shaping such that the transmitted power at plus or minus 25MHz is down by 60 dB [TSO C74C]. The receiver circuit has a threshold sensitivity of -70 dBm.

A proposed scheme[1] would use current transponder technology to transmit at random intervals GPS position and velocity along with barometric altitude in addition to the normal mode 3A/C responses. If widely used, any aircraft with a compatible receiver could have a cockpit display showing other aircraft in the area. The new system has been named "Tail Light", analogous to the tail light in a car at night or in the fog.

The proposed system would use the mode S downlink format signaling which is a PPM(Pulse Position Modulation) scheme with a 1 Mbit/s rate. A "1" is defined to be a 0.5us burst followed by 0.5us of off time. A "0" is defined to be 0.5us of off time followed by a 0.5us burst. The message is proceeded by a 8us sync pulse. Either 56 (single length) or 112 (double length) bits of data follow.

- For the double length message, 40 bits have been assigned for Forward Error Correction (FEC) using Reed-Solomon encoding. Since this is a short message, the optimal burst error capability is obtained[2] with a 5 bit t=4 or RS(31,23) code. This code can correct a 16 bit worst case burst error.
- Also, if erasure information can be provided by the receiver a burst error of 36 bits can be corrected effectively doubling the error correction capability[3]. Note that with PPM a simple system for obtaining erasure information is available. Since "00" and "11" are not defined, any bit received with these sequences should be flagged as an erasure. As these bits are arranged into 5 bit words for the decoder, the word would be marked as an erasure.
- In conclusion, the proposed system would be a benefit for general aviation which lacks a cost effective solution for collision avoidance. The FEC scheme proposed would greatly enhance overall system reliability. Lastly, the RS(31,23) decoder would be useful for any mobile system that uses short (61-155 bits) bursts of data.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

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3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS

Work In Progress

An errors and erasures decoder based on an algorithm presented by Jeng[3] has been prototyped in C and implemented in Verilog. The C prototype has been tested and verified with over 100 million random vectors with random combinations of errors and erasures. The Verilog implementation will be similarly tested out.

Based on information provided by Lincoln Laboratory[4][5] and a phone conversation with Dr. Orlando the emphasis of the simulation will be altered somewhat. Since the Mode S channel is operated at a high SNR and under line of sight conditions channel fading is not a normal concern and the BER is very low. However there is another more common source of burst errors. Mode A/C replies from other aircraft that interfere are named FRUIT (False Replies Unsynchronized in Time). These burst errors will be simulated both with and without erasure detection.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

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3/30/2000

References:

[1] Peshak, B. Keith; http://www.monarch-air.com/gaviation/

[2] B. Kamali, "Some new Outlooks on Burst Error Correction Capabilities of Reed-Solomon Codes with Applications in Mobile-Communications", Proceedings of IEEE VTC'98, Ottawa, Canada, May 1998, pp. 343-347.

[3] J. H. Jeng and T. K. Truong, "On Decoding of Both Errors and Erasures of a Reed-Solomon Code Using an Inverse-Free Berlekamp-Massey Algorithm", IEEE Transactions on Communications, VOL. 47, NO. 10, Oct. 1999, pp. 1488-1494

[4]V. A. Orlando, "Mode S Beacon System: A Functional Overview", Project Report ATC-150, Rep. NO. DOT/FAA/PM-89/7, Lincoln Lab. M.I.T., 29 August 1989

[5]V. A. Orlando and P. R. Drouilhet, "Mode S Beacon System: Functional Description", Project Report ATC-42 Rev. D, Rep. NO. DOT/FAA/PM-86/19, Lincoln Lab. M.I.T, Aug. 1986

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3/30/2000

Mode A Packet - Four digit squawk code from front panel is encoded in octal form.

Bit	Description
F1	1st Framing Bit - 1
C1	3rd Digit 1's Value
A1	1st Digit 1's Value
C2	3rd Digit 2's Value
A2	1st Digit 2's Value
C4	3rd Digit 4's Value
A4	1st Digit 4's Value
X	No Transmit - 0
B1	2nd Digit 1's Value
D1	4th Digit 1's Value
B2	2nd Digit 2's Value
D2	4th Digit 2's Value
B4	2nd Digit 4's Value
D4	4th Digit 4's Value
F2	2nd Framing Bit - 1
X	No Transmit - 0
X	No Transmit - 0
SPIP	Special Purpose ID Pulse; Front Panel Ident. Button.

Mode C Packet - Identical to Mode A packet.

Altitude encoded on 10 bits of the digit values.

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3/30/2000

Mode S Sync Pulse.

Time	Value
0-0.5US	1
0.5-1.0US	0
1.0-1.5US	1
1.5-3.5US	0
3.5-4.0US	1
4.0-4.5US	0
4.5-5.0US	1

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

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Tail Light Long Format Message, 112 bits.

Field	Length	Description
Preface	5 bits	TBD, possible DF26 or 11010 base 2.
Latitude	16 bits	Ones of degrees, minutes and tenths (DMM.M). Precision is 0.1 minutes = 600 feet. Period is 9 degrees, 59.9 minutes = 600 NM. The second byte, tens of minutes, only ranges from 0 through 5, thus doesn't use the MSB. Set that bit to 0 for north, and 1 for south. 4 numbers, 16 bits.
Longitude	16 bits	Similar to latitude. Set the MSB of the tens of minutes byte to 0 for west and 1 for east. From 70 through 80 degrees latitude send tens of degrees through whole minutes (DDMM). Above 80 degrees send whole degrees and tens of minutes (DDDM). 4 numbers, 16 bits.
Altitude	10 bits	From Altitude Encoder.
Speed	12 bits	000-999 knots. If the craft is traveling over 999 knots, send 999, don't blindly drop the leading byte and send 000. 3 numbers, 12 bits.
Course	12 bits	000-359 degrees true. Use the otherwise unused MSB of the hundreds of degrees to include the message validity flag. 3 numbers, 12 bits.
Stuff Bit	1 bit	TBD
FEC Parity	40 bits	RS(31,23) code. 5 bit symbols, t = 4.

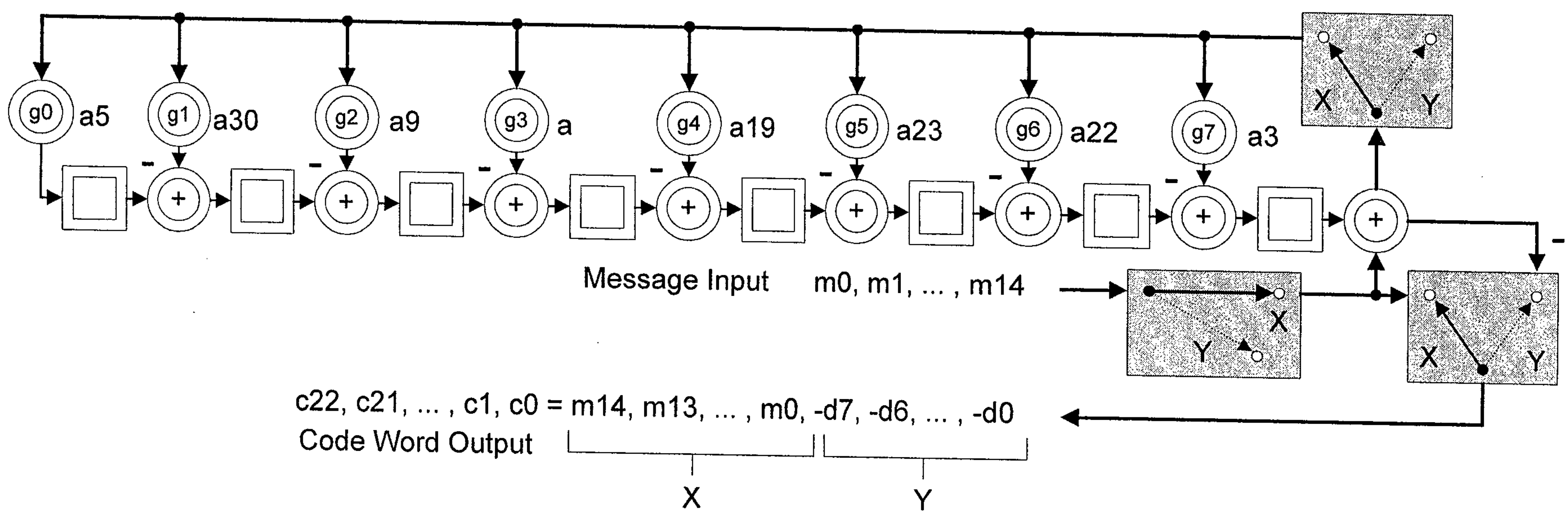
Tail Light Short Format Message, 56 bits.

Field	Length	Description
Preface	5 bits	TBD, possible DF27 or 11010 base 2.
Latitude	12 bits	Minutes and tenths (MM.M). Precision is 0.1 minutes = 600 feet. Period is 59.9' = 60 NM. The first byte, tens of minutes, only ranges from 0 through 5, thus doesn't use the MSB. Set that bit to 0 for north, and 1 for south. 3 numbers, 12 bits.
Longitude	12 bits	Similar to latitude. Set the MSB of the tens of minutes byte to 0 for west and 1 for east. From 70 through 80 degrees latitude send ones of degrees through whole minutes (DMM). Above 80 degrees send whole degrees only (DDD) and put the E/W bit in the otherwise unused first bit of the hundreds of degrees. 3 numbers, 12 bits.
Altitude	10 bits	From Altitude Encoder.
Speed	8 bits	10 knots precision, up to 990 knots. 2 numbers, 8 bits.
Course	8 bits	10 degrees precision, 000-350 degrees true. Use the otherwise unused MSB of the hundreds of degrees to include the validity flag. 2 numbers, 8 bits.
Parity	1 bit	Single parity bit for message.

RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

Reed Soloman (31,23) Encoder (Shortened)



RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

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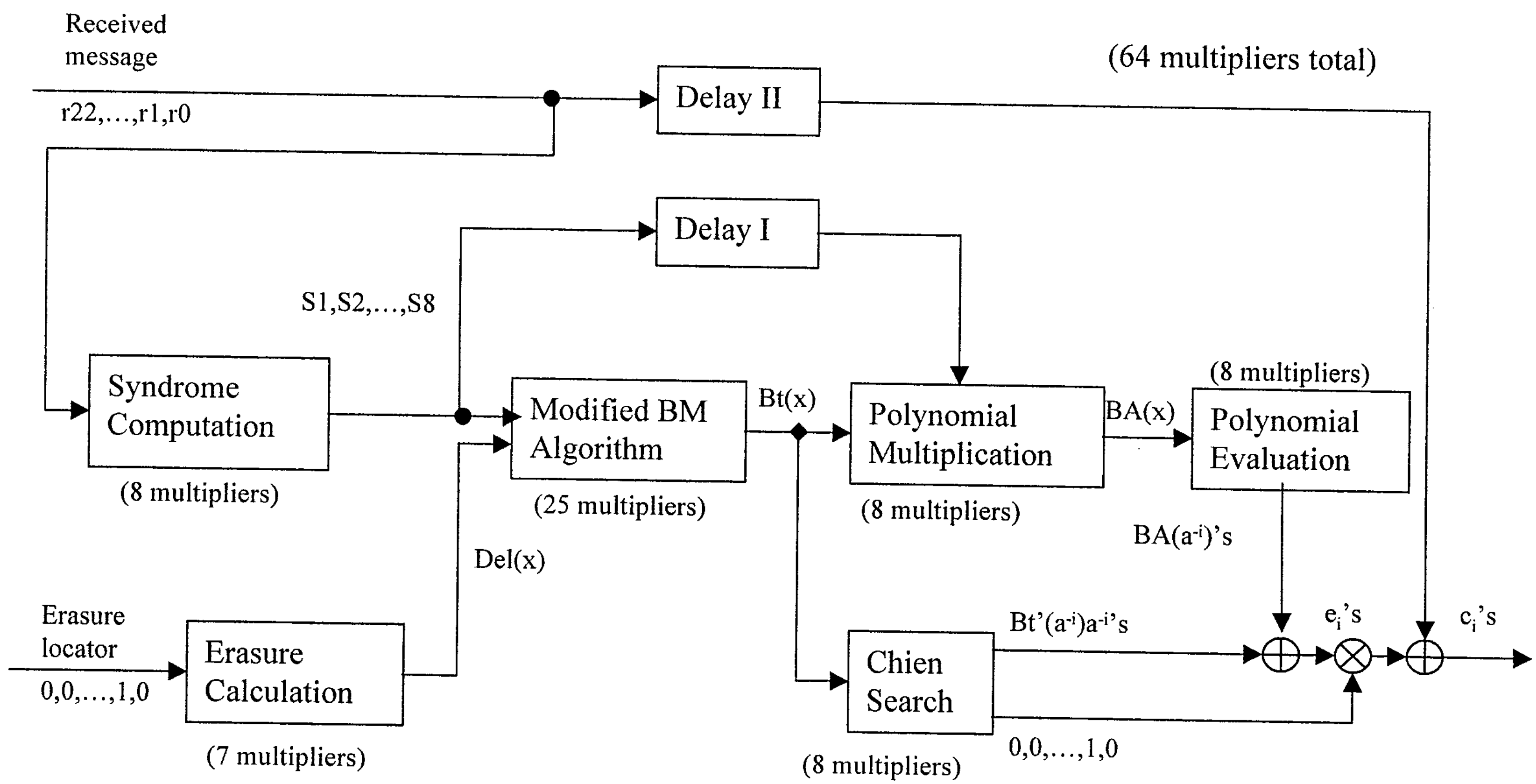
3/30/2000

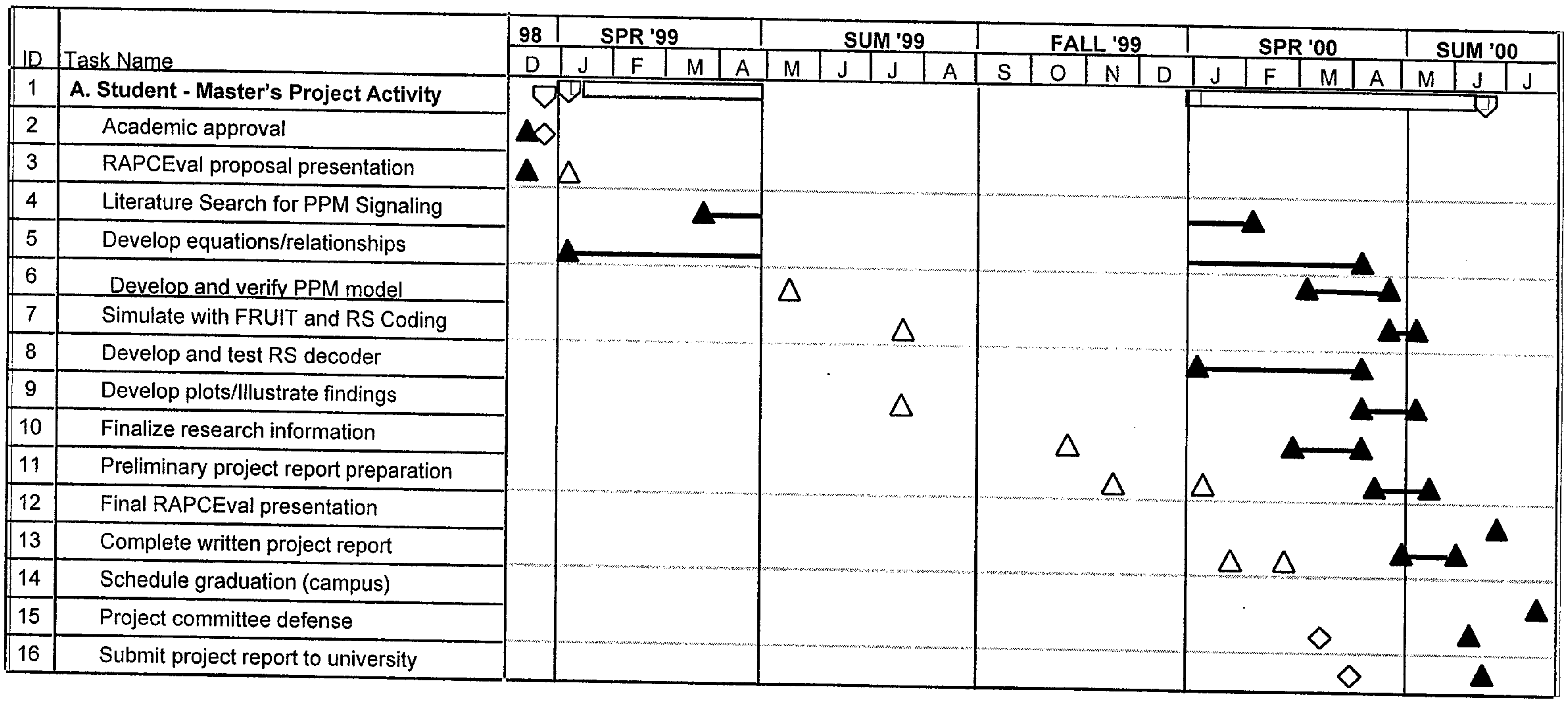
Reed Solomon (31,23) Decoder (Shortened)



RF RECEIVER AND PROCESSING CONCEPTS EVALUATION PROGRAM (RAPCEval)

Mark Napier
Presentation
3/30/2000

APPLICATION OF REED-SOLOMON ENCODING TO IMPROVE PROPOSED COLLISION AVOIDANCE SYSTEM BASED ON CIVILIAN ATCRBS



5.5 Thesis Report by Randy Ford

A revision in standard report style has been generated from the master's thesis written by Randy Ford. This document is reproduced here on the next 104 pages.

COMPARISON OF DIFFERENTIAL EVOLUTION
TO THE SIMPLEX METHOD IN
OPTIMIZATION DURING PASSIVE EMITTER LOCATION

by

JAMES R. FORD

B.E.E., Georgia Institute of Technology, 1986

Report Version, based on a
Project Report Submitted to the Graduate Faculty of
Mercer University School of Engineering

in Partial Fulfillment of the
Requirements for the Degree

MASTER OF SCIENCE IN ENGINEERING

MACON, GA
1998

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1 EXECUTIVE SUMMARY

1.1 OVERVIEW

This section presents results based on a master's degree thesis written by Randy Ford. The title of Randy's thesis was *Comparison Of Differential Evolution To The Simplex Method In Optimization During Passive Emitter Location.*

1.2 SUMMARY

In "An Efficient Method of Passive Emitter Location" Klaus Becker proposes using multiple frequency measurements by a moving sensor to generate a Cramer-Rao bound ellipsoid. This ellipsoid is then projected into the x-y plane to form an error surface that may be searched by generating a starting point and then minimizing the sum square error (SSE) using some optimization method. Once the emitter's location is found, the estimated emitter frequency is determined by obtaining a maximum likelihood (ML) value at that point.

A MATLAB simulator is the basis for the project. This emitter location simulator was modified slightly to call an external C++ dynamically linked library (dll) for minimization. One version calls a dll that uses the Nelder-Mead simplex minimization method. The other version calls a dll that uses Differential Evolution for minimization. Differential Evolution is a minimization technique developed by Kenneth Price and Rainer Storn based on genetic algorithms.

The primary objective of the project was to determine which optimization technique was the fastest while still providing an accurate answer. Both techniques were tested using the same sets of data on the same computer.

In a majority of the test cases it was possible to adjust the parameters of the Differential Evolution (DE) program to produce a faster and more accurate solution than the simplex program. The parameters which produced these results were not always the same for all data. A comparison of the results using two sets of generally successful parameters shows that in half of the cases the solutions were still faster and better than those produced by the simplex program.

Differential Evolution is a very promising tool for this application. Using passive measurements in a noisy environment, the DE simulators were faster than the simplex ones. Their accuracy overall was as good or better than the conventional simplex method. Further research into optimal parameter values and alternate crossover techniques could provide even better results from DE.

2 BACKGROUND

2.1 Passive Emitter Location

In "An Efficient Method of Passive Emitter Location," Klaus Becker proposes using multiple frequency measurements by a moving sensor to generate a Cramer-Rao bound ellipsoid. This ellipsoid is then projected into the x-y plane to form an error surface that may be searched by generating a starting point and then minimizing the sum square error (SSE) using some optimization method. Once the emitter's location is found, the estimated emitter frequency is determined by obtaining a maximum likelihood (ML) value at that point.

Determining the location of an emitter is a common task. When an emitter must be located without any active emissions by the searcher the task is more difficult. Becker's method allows a searcher to passively determine an emitter location even when noise is present.

Becker's method uses the minimization of the Sum Square Error (SSE) as the means to locate the transmitter. There are many different optimization or minimization techniques that will work. Two of the possibilities are the Nelder-Mead simplex method and a method called Differential Evolution.

2.2 The Nelder-Mead Simplex Method

A simplex, according to Chapter 10 of <u>Numerical Recipes in C</u>, is a "geometrical figure consisting, in N dimensions, of N+1 points (or vertices) and all their interconnecting line segments, polygonal faces, etc."[1] The Nelder-Mead simplex method is an optimization technique based on moving this N+1-dimensional shape on a search through the N-dimensional solution space. This is a standard optimization technique that requires no derivatives, only function evaluations. The simplex is said to move downhill because it moves away from high points toward low ones.

To initialize the search, N+1 initial points are chosen to form the initial simplex. This simplex then moves in a series of steps searching for the minimum.

The simplest step is called a reflection. A reflection moves the point of the simplex that has the highest value through the face opposite to it towards a lower point. The simplex is thereby reflected away from the high point. (See Figure 1.)

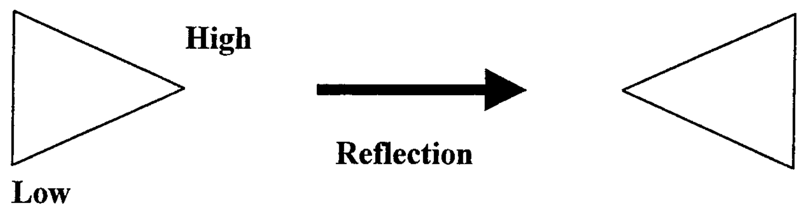


Figure 1: Reflection

A similar step is called reflection and expansion. In this step the simplex is not only reflected away from the high point, it is expanded in the direction of the lower point. This allows bigger steps to be taken in the search. (See Figure 2.)

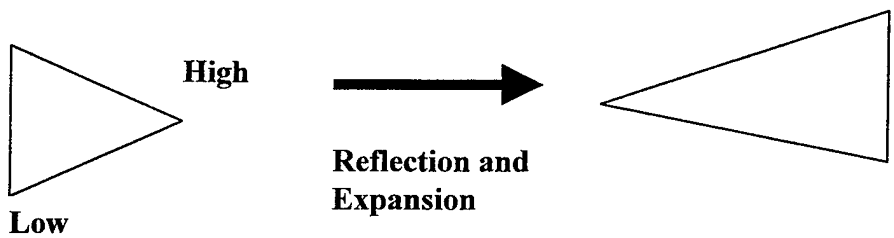


Figure 2: Reflection and Expansion

Contraction in one dimension is used when the search reaches a valley floor of low points. The simplex just contracts in the direction facing the high point. The simplex is described as trying to ooze down the valley. (See Figure 3.)

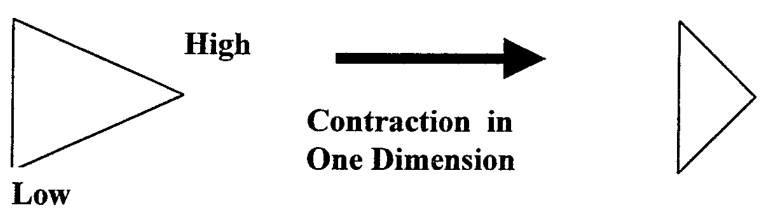


Figure 3: Contraction in One Dimension

When a simplex contracts along all dimensions towards its lowest point, it is said to be moving through the "eye of a needle." Simplex routines are often called amoebas because of their behavior during contraction steps. (See Figure 4.)

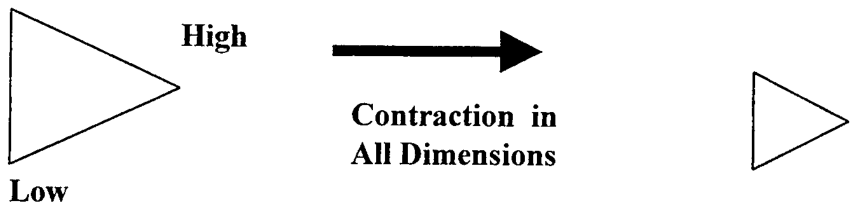


Figure 4: Contraction in All Dimensions

Nelder-Mead simplex searches usually terminate when the distance moved in a step is less than some tolerance or the decrease in function value during a step is less than some tolerance.

2.3 Differential Evolution

Differential Evolution is a minimization technique developed by Kenneth Price and Rainer Storn. It is introduced in the article "Differential Evolution" in the April 1997 issue of Dr. Dobb's Journal, where it is described as "A simple evolution strategy for fast optimization."[2] It is based on genetic algorithms but, unlike many genetic algorithms, it manipulates real values directly instead of translating them into some symbol alphabet.

A genetic algorithm is a probabilistic search technique that makes use of the principles of genetics. Dr. John H. Holland was the developer. An evolutionary strategy is a form of genetic algorithm that is especially useful in minimizing functions with real variables and many local minima. Differential Evolution is an evolutionary strategy.

Where standard genetic algorithms encode points in strings of symbols referred to as "chromosomes", DE uses the actual floating-point values of the numbers. Genetic algorithms usually refer to a point's value as its "fitness" and attempt to maximize it. In DE, the point's value is often called its "cost" and is minimized. Standard genetic algorithms implement mutation by simply swapping symbols in a chromosome. This often results in large moves inside the search area. In DE, mutation is implemented by addition. This makes incremental search easier.

The first step in DE is to form two real-valued arrays of size NP. These arrays, of dimension D, are the current population and the next generation. Reasonable limits on the parameter values are determined from the problem. The initial population is generated and each member evaluated to determine its cost. The cost of each population member is stored in the cost array.

Each member of the current population takes its turn as the "target" vector for the operations of mutation, crossover, and selection. A scaling factor F is chosen. Its value is

greater than 0, but less than or equal to 1.2. Optimal values for F are between .4 and 1.0. A crossover constant CR, ranging from 0 to 1 inclusive, is assigned next.

Mutation is an operation that forms a noisy random vector from a randomly chosen population member. First, the difference between two randomly chosen population members is determined:

$$x_a - x_b$$

Then this difference is multiplied by the scaling factor F:

$$F * (x_a - x_b)$$

Add this to a randomly chosen population member x_c to form the noisy random vector x_c':

$$x_c' = x_c + F * (x_a - x_b)$$

Crossover, also called recombination, is an operation that creates a trial vector x_t to be used during selection. (See Figure 5.) The trial vector is formed by combining the target vector with the noisy random vector x_c'. In a set of D-1 experiments is conducted starting at a randomly selected parameter of the target vector. For each parameter, CR is compared to a uni-

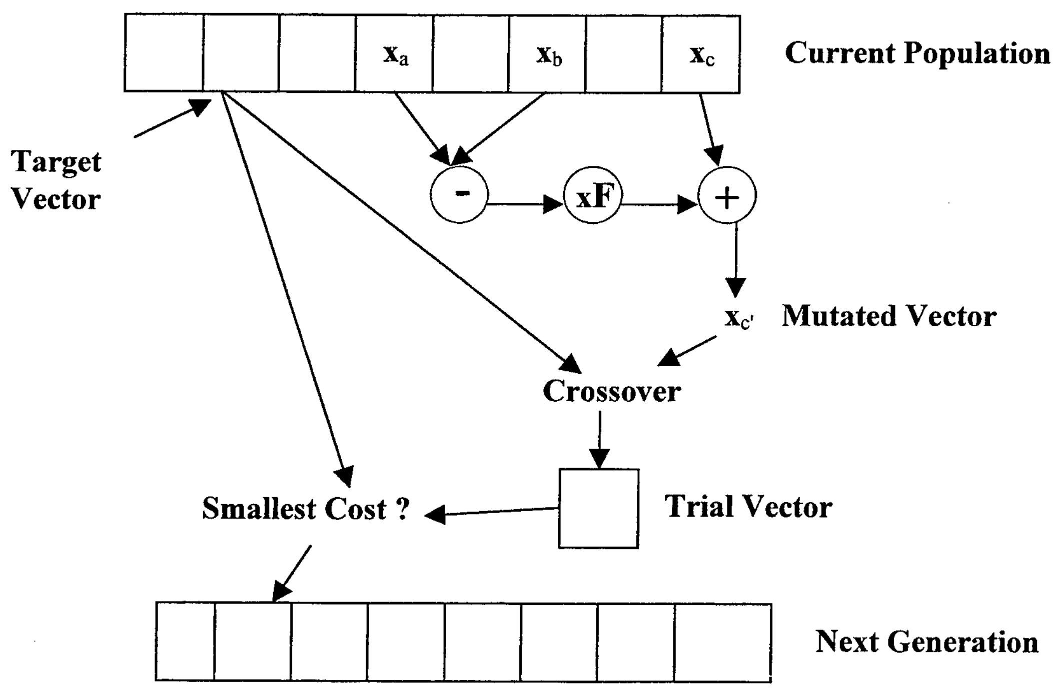


Figure 5: Differential Evolution

formly distributed random number from 0 to 1. If the number is greater than CR, the trial vector's parameter comes from the target. If the number is less than or equal to CR, the trial vector's parameter comes from x_c'. In order to make sure that the trial vector always differs from the target in some way the D^{th} (last) parameter is always taken from the noisy random vector x_c'.

Selection is a process that determines the contents of the next generation array. The cost of each trial vector is compared to the cost of the target vector. The vector with the lowest cost is moved to the next generation array. If the trial vector wins, its cost replaces the target's cost in the cost array.

After each vector in the current population array has been targeted and the next generation array is complete, the next generation array becomes the current population array. Trials continue for a pre-set number of iterations or until the cost of the best vector is less than or equal to a pre-set value. Figure 5 illustrates a DE trial.

A MATLAB simulator is the basis for the project. This simulator of the passive emitter location process was modified slightly to call an external C++ dll for minimization. One version calls a dll that uses the Nelder-Mead simplex minimization method. The other version calls a dll that uses DE for minimization.

The primary objective of the project was to determine which optimization technique was the fastest while still providing an accurate answer. The simplex technique is a proven, reliable way to find a minimum. The DE method, based on the artificial intelligence concept of genetic algorithms, is a powerful but very non-deterministic technique. Both techniques were tested using the same sets of data on the same computer.

[1] From Numerical Recipes in C (p. 408), by William H. Press, Saul A. Teukolsky, William T. Vetterling, and Brian P. Flannery, 1992, New York, NY: Cambridge University Press. Copyright 1992 by Cambridge Univeristy Press.

[2] From "Differential Evolution," by Kenneth Price and Rainer Storn, 1997, Dr Dobb's Journal, 264, p. 18 . Copyright 1997 by Miller Freeman , Inc.

3 REVIEW OF THE LITERATURE

3.1 Articles

3.1.1 "An Efficient Method of Passive Emitter Location"

"An Efficient Method of Passive Emitter Location" (Klaus Becker, IEEE Transactions on Aerospace and Electronic Systems, Vol. 28, No. 4, October 1992) discusses passive emitter location using bearing measurements, frequency measurements, and a combination of the two. By making multiple frequency measurements, a moving sensor can generate a Cramer-Rao bound ellipsoid. This ellipsoid is then projected into the x-y plane to form an error surface that may be searched by generating a starting point and then minimizing the SSE using some optimization method. Once the emitter's location is found, the estimated emitter frequency is determined by obtaining a ML value at that point.

This article forms the basis for the MATLAB simulator that is used in this project to test these two optimization methods.

3.1.2 "Differential Evolution"

"Differential Evolution" (Kenneth Price and Rainer Storn, Dr. Dobb's Journal, April 1997, Issue #264) discusses a minimization technique based on genetic algorithms. Unlike many genetic algorithms, it manipulates real values directly instead of translating them into some symbol alphabet. Differential Evolution implements mutation using addition instead of symbol-swapping which allows incremental searching of the solution space. The DE minimization technique is fast, easy to implement, and powerful. This article forms the basis for the C++ dll called by the MATLAB simulator during the search of the error surface.

3.2 Texts

3.2.1 "Emitter Location"

"Emitter Location" (Chapter 5 of Electronic Intelligence: The Interception of Radar Signals, Richard G. Wiley, Artech House, 1985).

Discusses the methods of using measurements from various interceptors to locate and identify radar emitters. The classic Angle of Arrival technique and the Time Difference of Arrival technique were described. This chapter provided important background information.

3.2.2 "Minimization or Maximization of Functions"

"Minimization or Maximization of Functions" (Chapter 10 of Numerical Recipes in C, 2nd Edition, William H. Press, Saul A. Teukolsky, William T. Vetterling and Brian P. Flannery).

Describes the Nelder-Mead simplex method, an optimization technique based on moving an N+1-dimensional shape called a simplex through a search through an N-dimensional solution space. This is a standard optimization technique requires no derivatives, only function evaluations. This chapter forms the basis for the C++ dll called by the MATLAB simulator during the search of the error surface.

3.2.3 "Genetic Algorithms"

"Genetic Algorithms" (Chapter 14 of An Introduction to Optimization, Edwin K.P. Chong and Stanislaw H. Zak).

Describes genetic algorithms, a probabilistic search technique based on genetics. Strings of symbols called chromosomes represent values in the solution space. By performing crossover and mutation on a population of these chromosomes, genetic algorithms create new populations with higher and higher objective function values. This chapter provided important background information for the DE search.

3.3 Web Sites

3.3.1 Nova Genetica

[www.aracnet.com/~wwir/repos.html]

The Nova Genetica web site contains a large amount of background information on genetic algorithms as well as a large amount of source code. This site explains important differences between regular genetic algorithms and traditional optimization algorithms. It discusses the use of coded representations of parameters, the use of a population of solution vectors, the use of the function without any derivatives, and the probabilistic, as opposed to deterministic, transition rules. This site provided important background information for the DE search.

3.3.2 Differential Evolution

[www.icsi.berkeley.edu/~storn/code.html]

The DE web site contains important background information on DE as well as the DE source code. It describes recommendations for initial parameter values as well a adjustments for various search situations. This site provided important background information for the DE search.

3.3.3 Ron de Beer's Web Page

[dutnsic.tn.tudelft.nl:8080/c59_to_html/node28.html]

Ron de Beer's web site at the University of Technology Delft in The Netherlands contains tutorials on the Maximum Likelihood method, the Fisher Information Matrix, and the

Cramer-Rao Bound. This site provided important mathematical background information on the MATLAB simulator.

4 STATEMENT OF THE PROBLEM

4.1 Problem Statement

Determining the location of an emitter by taking frequency measurements from a moving sensor platform under emission restrictions is an important military application. Klaus Becker's article "An Efficient Method of Passive Emitter Location" proposes using multiple frequency measurements to generate a Cramer-Rao bound ellipsoid. This ellipsoid is then projected into the x-y plane to form an error surface. The loss of the third parameter (z) increases detection speed while sacrificing little in position information. The error ellipse will be searched by generating a starting point and by minimizing the SSE using some optimization method. Once the emitter's location is found, the estimated emitter frequency is determined by obtaining a ML value at that point.

There are many different optimization or minimization techniques that will work. Two of the possibilities are the Nelder-Mead simplex method and a method called DE.

The Nelder-Mead simplex method is a traditional, deterministic, technique that moves downhill through the solution space by moving an N+1-dimensional shape called a simplex towards the lowest point. This is an iterative method that is fast and reliable.

The DE method developed by Kenneth Price and Rainer Storn is a nondeterministic search technique based on genetic algorithms. Unlike regular genetic algorithms, DE uses real-valued parameters instead of symbols. It mutates vectors by adding a differential derived from the solution space instead of flipping symbols.

4.2 Objective

The primary objective of this project was to determine which of the two above minimization techniques produce a solution faster. In order to do this, the MATLAB simulator provided by the Mercer Engineering Research Center was modified slightly. Two modified versions were developed. One calls an external C++ dll that implements the Nelder-Mead simplex method for minimization. The other calls a C++ dll that implements DE for minimization. Identical data was run through both versions of the program and the results compared. The primary objective was to determine the fastest application, but the accuracy of the solutions is also very important. Therefore, the position error in the results was also compared.

5 METHODS

5.1 Environment

The tests in this project were run on a Pentium^{TM} 133 MHz processor under Windows 98 using MATLAB version 4.2. The C++ dlls were compiled under Borland C++ version 4.51 using command line switches supplied by the MATLAB file cmex.bat.

5.2 The MATLAB Simulator

The MATLAB emitter location application, which is the basis for this research project simulates multiple frequency measurements taken from a moving platform. After reading in baseline position, frequency, and other data from an external file, it runs the calculations to create the error ellipse that needs to be searched for the emitter position. The original version used the MATLAB function fmins to do the search using the Nelder-Mead simplex method. To fairly evaluate the speed of these minimization techniques, the new versions both call external C++ dlls called MATLAB MEX files.

A starting point for the error surface search is input. The error surface is then searched by a set of Monte Carlo simulations. In each Monte Carlo run, a random amount of noise is added to the position, velocity, and frequency data to provide measured position, measured velocity, and measured frequency. Identical random noise data is added for the runs of both versions of the simulator. Data is passed to the search dll.

The simplex dll receives the starting point, number of time samples, time, measured frequency, measured position, measured velocity, and height. Note that height data is passed to allow for possible future expansion of the simulator. (See Figure 6.) The DE simulator receives four additional pieces of information that set the DE search parameters. (See Figure 7.) The additional items of information are the population size, scaling factor, crossover constant, and number of iterations. Both dlls return an emitter location and the ML emitter frequency. The simulator then displays the output locations, the error distance of each point, the average output error distance over all of the Monte Carlo runs, and the ML emitter frequencies. The error distance is the distance of the output location from the actual emitter location recorded in the data file. It the presence of noise this will always be nonzero. The output locations from the Monte Carlo runs are then plotted and displayed with the error ellipse.

There were four versions of each MATLAB simulator. Files nmloc.m and deloc.m both used file data.m. Files nmloc1.m and deloc1.m used data1.m. Files nmloc2.m and deloc2.m used data2.m. Files nmloc3.m and deloc3.m used data3.m.

Each version invokes an external C++ program floatf.exe which forces Windows 98 to load win87em.dll. This allows 64-bit floating-point emulation which lets the search run about six times faster. This is run just before the information from the data.m file is loaded.

The four data files contain different emitter location and emitter frequency values. The other data, mostly having to do with the sensor platform's movement and sampling, is identical in all data files.

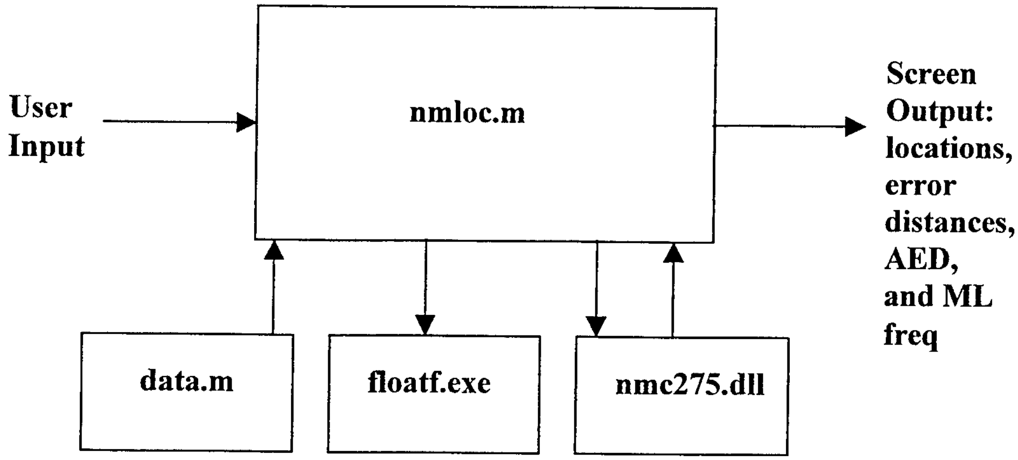


Figure 6: Overview of Simplex MATLAB Simulator

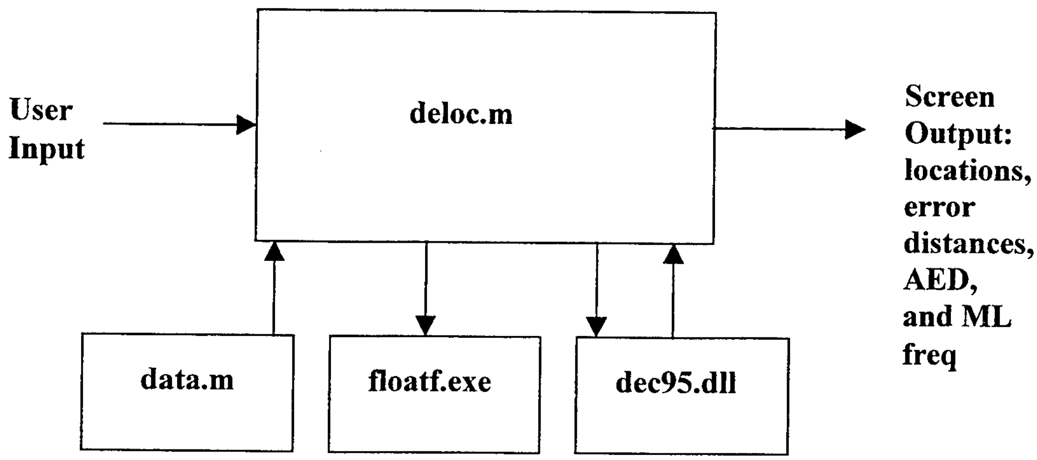


Figure 7: Overview of Differential Evolution MATLAB Simulator

5.3 The Nelder-Mead Simplex DLL

The simplex dll, nmc275.dll, is based on a program in Chapter 10 of Numerical Recipes in C. The dll is passed the search starting point in variable pv and the other search data in the pointer variables ndt_ptr, time_ptr, frm_ptr, xyzm_ptr, xyzvelm_ptr, ht_ptr. It calls get_starting_simplex to generate two other points to form an initial simplex. The amoeba routine then searches the error space. It runs iterations until the fractional range from the highest to the lowest point in the simplex is less than some tolerance value. Each iteration tries one or more of the simplex strategies: reflection, reflection and expansion, contraction in one dimension, or contraction in all dimensions. The best point of the simplex is then chosen as the output point. Each iteration involves the amotry function evaluating the value of the function called funk at the simplex points. This function is based on the file dopfit.m that was used to provide the value of SSE in the original simulator. Finally, the ML frequency value for the output point is calculated for output. This is done by

sending the low point vector, number of time samples, time, measured frequency, measured position, measured velocity and height to function get_f0e. This function is very similar to funk, but it passes back the ML frequency for the low vector instead of its cost. The simplex dll then returns the low vector in variable pv2 and its ML frequency in variable f0e2 to the MATLAB simulator. (See Figure 8.)

5.4 The Differential Evolution DLL

The DE dll, dec95.dll, is passed the search starting point in variable pv and the other search data in the pointer variables ndt_ptr, time_ptr, frm_ptr, xyzm_ptr, xyzvelm_ptr, ht_ptr. It receives the parameter data in the variables np, f, cr, and iter.

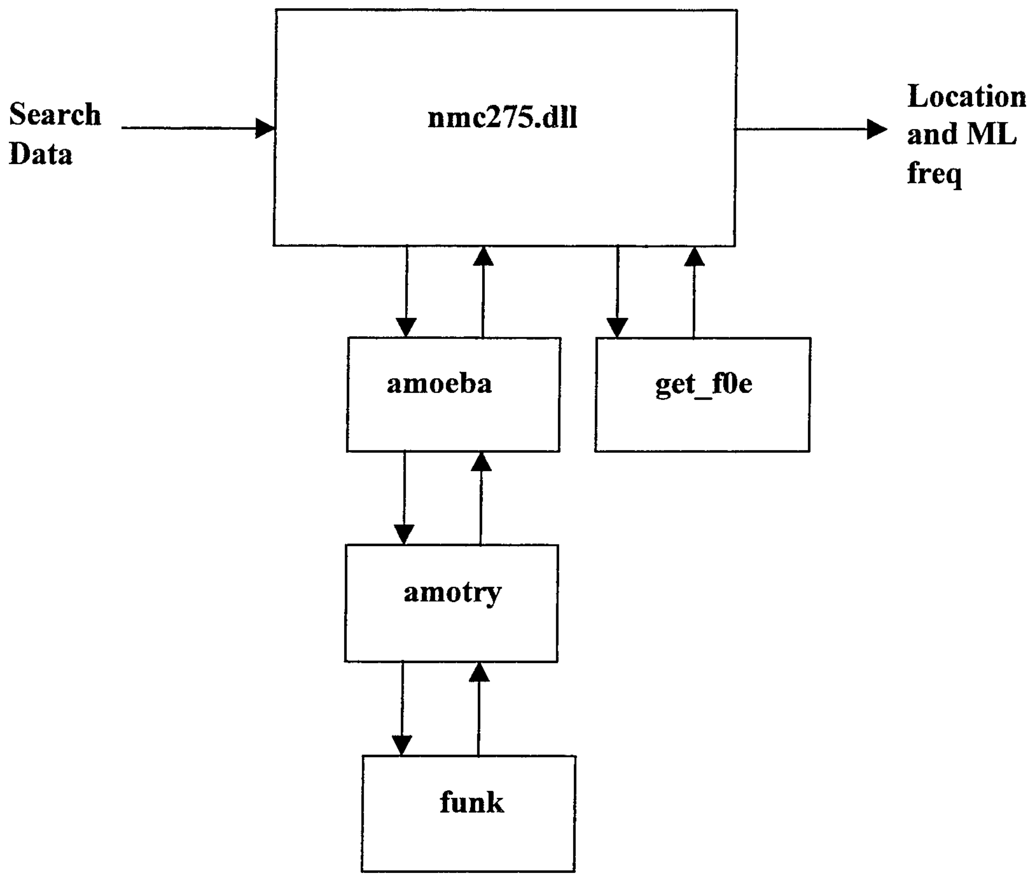


Figure 8: Overview of the Nelder-Mead Simplex DLL

The DE dll initializes its random number generator and then sets up upper and lower bounds based on the starting point input into MATLAB. These are used to check to values of the first randomly-generated population of vectors.

The current generation population array and the cost array are set up. These are sent to the DE minimizer function called de_minimizer, along with the starting point, population size, number of time samples, time, measured frequency, measured position, measured

velocity, height, scaling factor F, crossover constant CR, and the number of iterations. Note that height data is passed to allow for possible future expansion of the simulator.

The DE minimizer reinitializes the random number generator and then sets up the next generation array. The lowest cost vector and its corresponding index are determined next.

The DE minimizer then iterates through a set number of trials. During every trial, each member of the current population array serves as the target once. It is compared during the trial to a trial vector that is built from parameters taken from the target vector and a noisy random vector. The minimizer finds the difference between two randomly chosen vectors and multiplies it by the scaling factor F. This weighted difference is then added to a third randomly chosen vector to form the mutated or noisy random vector. This procedure is one of the main differences between DE and traditional genetic algorithms. Mutation is accomplished by addition and the amount added is taken from the context of the problem by creating the weighted difference.

The next operation is crossover that creates the trial vector. One of the two parameters of the target vector is chosen at random. A random number is generated and compared to the crossover constant CR. If the random number is greater than CR, the trial vector gets its parameter from the target, otherwise the parameter comes from the noisy random vector. In order to insure that the trial vector is always different from the target vector, the other parameter is always taken from the noisy random vector.

The cost of the trial vector is determined by sending the trial vector, number of time samples, time, measured frequency, measured position, measured velocity and height to function funk. This function is based on the file dopfit.m that was used to provide the value of the SSE in the original simulator. In this case it provides the cost value for the trial vector. The vector having the lowest cost is placed in the next generation array. If the trial vector has the lowest cost, its cost replaces the target vector's cost in its slot in the cost array. If the trial vector's cost is the lowest in the cost array, its value is recorded as the new low and its index is recorded as the location of the new lowest vector.

The next vector in the current generation then becomes the new target. This process continues until the entire current population has been targeted. Then the next generation array becomes the new current population array. This array is targeted during the next iteration. This process continues until the preset number of iterations input into MAT-LAB is reached. The lowest cost vector at this point is passed back in the x array.

The low vector, number of time samples, time, measured frequency, measured position, measured velocity and height are passed to function get_f0e. This function is very similar to funk, but it passes back the ML frequency for the low vector instead of its cost. The DE dll then returns the low vector and its ML frequency to the MATLAB simulator. (See Figure 9.)

5.5 Comparison Tests

The heart of the project is in the comparison tests. These tests, contained in Test Sets 1-12, directly compare the performance of the minimization methods. Each test set is based on a different set of starting (x,y) coordinates. These coordinates were taken from the error ellipse formed from the data in the data.m files used by the MATLAB simulators. The starting points were chosen to illustrate different types of search behavior. Some result in both simulators with good results on the first run. Others show both

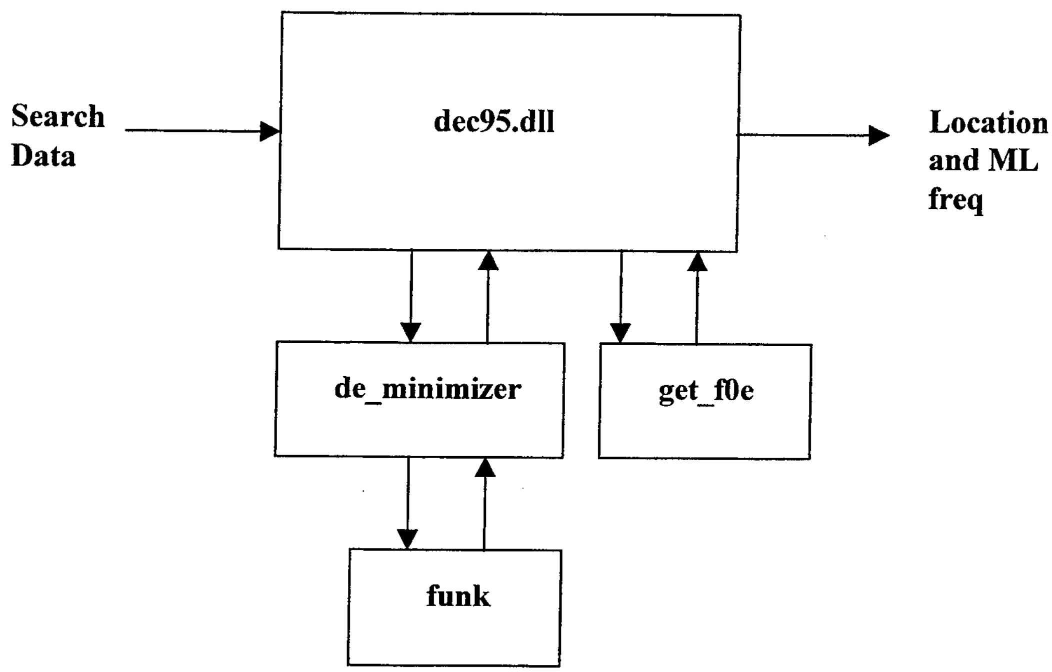


Figure 9: Overview of the Differential Evolution DLL

simulators with bad results for the first run. Still other points show mixed results.

Test Sets 1-3 use data.m and compare simulators nmloc.m and deloc.m. The transmitter location in this data file is x=0 meters, y=0 meters. The sensor platform starts out at x=-82,820 meters and y=309,100 meters moving at 300 meters per second. The distance from the sensor platform to the transmitter starts at 320,000 meters. By the time the platform finishes its sinusoidal flight path it is 319,240 meters from the transmitter. The average distance from the sensor to the emitter during the flight is 319,620 meters.

Test Sets 4, 5, and 6 use data1.m and compare simulators nmloc1.m and deloc1.m. The transmitter location in this data file is x=1000 meters, y=2000 meters. The sensor platform starts out at x=-82,820 meters and y=309,100 meters moving at 300 meters per second. The distance from the sensor platform to the transmitter starts at 318,330 meters.

The sensor is 317,560 meters from the emitter at the end of the flight. The average distance from the sensor to the emitter during the flight is 317,560 meters.

Test Sets 7, 8, and 9 use data2.m and compare simulators nmloc2.M and deloc2.M. The transmitter location in this data file is x=-3000 meters, y=-1500 meters. The sensor platform starts out at x=-82,820 meters and y=309,100 meters moving 300 meters per second. The distance from the sensor platform to the transmitter starts at 320,690 meters and finishes at 319,960 meters. The average distance from the sensor to the emitter during the flight is 320,320 meters.

Finally, Test Sets 10-12 use data3.m and compare simulators nmloc3.M and deloc3.M. The transmitter location in this data file is x=4000 meters, y=-5000 meters. The sensor platform starts out at x=-82,820 meters and y=309,100 meters moving 300 meters per second. The distance from the sensor platform to the transmitter starts at 325,880 meters. By the time the platform finishes its sinusoidal flight path it is 325,090 meters from the transmitter. The average distance from the sensor to the emitter during the flight is 325,480 meters.

Each of the nmloc and deloc simulators is identical except for the data file loaded.

Both versions of the simulator, nmloc and deloc, use the same random number seed and initialize the random number generator in the same way. This means that the noise effects in both simulations are identical. Both simulators were timed manually with the same stopwatch.

The first test of each of the comparison test sets is called the baseline run. It represents a search with no effort to adjust the DE parameters. The other DE tests in the set are compared to it. The simplex dll does not have parameters to adjust so each of its runs during the test set will be set up just like the baseline run. The Average Error Distance (AED) will be the same throughout the test set, but the time elapsed will vary slightly. The DE dll has five parameters that are adjusted during each test run to gauge their effects on the speed and accuracy of the simulator as compared to the baseline run of the simplex dll.

The population size, NP, the scaling factor F, the crossover constant CR, and the number of iterations are all adjustable. The DE baseline run of every comparison test sets the NP at 10, F at .9, CR at .5, and iterations at 10. The only exception is Test Set 1 that starts with 100 iterations. This was adjusted to 10 after several tests.

The results of the comparison tests are recorded in tables. Each Test Set has its own table that shows the simplex run and then the DE run for each test number. Recorded in the table are the starting conditions for the test set (in the table header), the test number, the MATLAB simulator, the C++ dll name, the population size (if applicable), the scaling factor (if applicable), the crossover constant (if applicable), the number of iterations (if applicable), and the results. The results are the time elapsed and the AED. Screen logs and graphical output from selected comparison tests are included in Appendix A.

5.6 Other Tests

5.6.1 Supplemental Parameter Tests

In order to compare the results of running the DE simulator with certain groups of "good" parameter values against all of the starting coordinates it was necessary to run Test Set 13. This test set consists of Tests 121, 122, and 123.

5.6.2 Monte Carlo Tests

All of the comparison tests were run with 10 Monte Carlo simulations. Test Set 14 was run in order to test the effects of running fewer Monte Carlo simulations and more Monte Carlo simulations on the time elapsed and AED. Tests 124 - 135 repeat previous tests from each data set with 5, 20, and 50 Monte Carlo runs each.

5.6.3 Average Error Distance Repeatability Tests

Because of the nature of the pseudo-random number generators used during by the MATLAB simulators and the DE C++ dll, the AED will be the same for tests repeated with the same starting data and input data. This is because the seed used in both cases is the same when the test is repeated. Test Set 15 illustrates this fact by re-running Tests 19, 44, 75, and 99 and comparing the results with the previous runs. This test set consists of Tests 136, 137, 138, and 139, one test using each data file.

6 RESULTS AND DISCUSSION

6.1 Test Set 1

(See Table 1.)

Table 1 Test Set 1

Test Set: 1
Data File: DATA.M
Number of Monte Carlo runs: 10
Starting x Coordinate: -247,010
Starting y Coordinate: 938,510
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
1	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.43	1.62 e+5 / 51%
	deloc.m	dec95	10	0.9	0.5	100	10.86	8.20 e +4 / 26%
2	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.35	1.62 e +5 / 51%
	deloc.m	dec95	10	0.9	0.5	50	6.24	8.20 e +4 / 26%
3	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.35	1.62 e +5 / 51%
	deloc.m	dec95	10	0.9	0.5	25	3.99	1.08 e +5 / 34%
4	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.28	1.62 e +5 / 51%
	deloc.m	dec95	10	0.9	0.5	20	3.52	1.15 e +5 / 36%
5	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.25	1.62 e +5 / 51%
	deloc.m	dec95	10	0.9	0.5	15	3.06	9.78 e +4 / 31%
6	nmloc.m	nmc275	n/a	n/a	N/a	n/a	3.32	1.62 e +5 / 51%
	deloc.m	dec95	10	0.9	0.5	10	2.67	1.71 e +5 / 53%
7	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.26	1.62 e +5 / 51%
	deloc.m	dec95	10	1.1	0.5	10	2.63	1.86 e +5 / 58%
8	Nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.19	1.62 e +5 / 51%
	Deloc.m	dec95	10	0.7	0.5	10	2.65	1.17 e +5 / 37%
9	Nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.28	1.62 e +5 / 51%
	Deloc.m	dec95	10	0.5	0.5	10	2.66	2.10 e +4 / 7%
10	Nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.62 e +5 / 51%
	Deloc.m	dec95	10	0.5	0.3	10	2.82	3.31 e +4 / 10%

The simplex program is off in this test set with a tight grouping outside the ellipse. The DE program has a very high time elapsed in the baseline run as well as a high AED. In Test 6, the time elapsed is below the simplex number with 10 iterations, but the AED is still high, higher than the simplex program. Test 9 has the lowest AED of this test set for the DE program. It is still high, but it beats the simplex number. The scaling factor is set at 0.5 and the crossover constant is set at 0.5. Dropping the crossover constant to 0.3 failed to lower the AED.

6.2 Test Set 2

The simplex program does well in this test set with a low AED. The DE program is off on the baseline run with a tight grouping. The DE program is faster than the simplex, even in the baseline run In Test 14, the DE program has its best run for this test set. It is faster and has a slightly lower AED than the simplex program. The scaling factor is set at 0.5 and the crossover constant is set at 0.3. Attempts to improve the AED by further lowering the scaling factor were not successful. (See Table 2.)

Table 2: Test Set 2

Test Set: 2 Data File: DATA.M Number of Monte Carlo runs: 10 Starting x Coordinate: 77,510 Starting y Coordinate: -305,660 SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
11	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.13	1.89 e +3 / .6%
	deloc.m	dec95	10	0.9	0.5	10	2.82	1.62 e +5 / 51%
12	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.05	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.5	10	2.76	2.30 e +4 / 7%
13	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.23	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.7	10	2.68	1.63 e +5 / 51%
14	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.25	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.3	10	2.63	1.58 e +3 / .5%
15	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.20	1.89 e +3 / .6%
	deloc.m	dec95	10	0.3	0.3	10	2.62	8.58 e +4 / 26%
16	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.36	1.89 e +3 / .6%
	deloc.m	dec95	10	1.1	0.3	10	2.65	1.70 e +5 / 53%
17	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.39	1.89 e +3 / .6%
	deloc.m	dec95	10	0.2	0.3	10	2.65	1.22 e +5 / 38%
18	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.11	1.89 e +3 / .6%
	deloc.m	dec95	10	0.3	0.4	10	2.67	1.59 e +5 / 50%
19	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.09	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.4	10	2.67	1.19 e +4 / 4%
20	nmloc.m	nmc275	n/a	n/a	n/a	n/a	2.97	1.89 e +3 / .6%
	deloc.m	dec95	10	0.6	0.6	10	2.66	1.60 e +5 / 50%

6.3 Test Set 3

In Test 21, the baseline for this test set, the simplex program is off in a loose grouping. The DE program is faster on the baseline, but its AED is higher. The DE has its lowest AED in Test 22 with a loose grouping. The AED is still high, but it is lower than the simplex number. The scaling factor is set at 0.5 and the crossover constant is set at 0.3. Raising and lowering the scaling factor and raising the crossover constant didn't improve the AED. Lowering both the population size and the number of iterations also did not improve the AED. (See Table 3.)

Table 3: Test Set 3

Test Set: 3
Data File: DATA.M
Number of Monte Carlo runs: 10
Starting x Coordinate: -253,800
Starting y Coordinate: 969,680
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
21	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.59	1.62e +5 / 51%
	deloc.m	dec95	10	0.9	0.5	10	2.76	1.77 e +5 / 55%
22	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.3	10	2.48	3.51 e +4 / 11%
23	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.35	1.62 e +5 / 51%
	deloc.m	dec95	10	0.7	0.3	10	2.66	9.51 e +4 / 30%
24	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.34	1.62 e +5 / 51%
	deloc.m	dec95	10	0.3	0.3	10	2.69	1.09 e +5 / 34%
25	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.40	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.6	10	2.66	1.55 e +5 / 48%
26	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.31	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.9	10	2.64	1.59 e +5 / 50%
27	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.52	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.3	8	2.51	4.33 e +4 / 14%
28	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.36	1.62 e +5 / 51%
	deloc.m	dec95	8	0.5	0.3	10	2.46	1.37 e +5 / 43%
29	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.26	1.62 e +5 / 51%
	deloc.m	dec95	8	0.5	0.3	9	2.34	1.27 e +5 / 40%
30	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.40	1.62 e +5 / 51%
	deloc.m	dec95	8	0.5	0.3	7	2.23	1.33 e +5 / 42%

6.4 Test Set 4

The simplex program gets a good AED on the baseline run for this test set. The DE baseline is, as usual, faster but has a much higher AED. The DE program is faster in all but Test 37, but it never has a lower AED. It comes closest in Test 40 with a population of 8, a scaling factor of 0.4, and a crossover constant of 0.3. (See Table 4.)

Table 4: Test Set 4

Test Set: 4
Data File: DATA1.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 72,770
Starting y Coordinate: -281,540
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
31	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.13	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.9	0.5	10	2.76	1.64 e +5 / 52%
32	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.3	10	2.86	1.44 e +4 / 5%
33	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.04	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.5	10	2.66	5.77 e +4 / 18%
34	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.16	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.2	10	2.79	2.87 e +4 / 9%
35	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.14	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.3	10	2.76	5.75 e +3 / 2%
36	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.18	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.3	0.3	10	2.82	2.72 e +4 / 9%
37	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.12	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.3	12	3.18	5.48 e +3 / 2%
38	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.15	1.77 e +3 / .6%
	deloc1.m	dec95	11	0.4	0.3	10	2.80	1.65 e +5 / 52%
39	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.15	1.77 e +3 / .6%
	deloc1.m	dec95	12	0.4	0.3	10	2.90	1.67 e +5 / 52%
40	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.16	1.77 e +3 / .6%
	deloc1.m	dec95	8	0.4	0.3	10	2.55	4.24 e +3 / 1%

6.5 Test Set 5

The simplex program gets a good AED on the baseline run for this test set. The DE baseline is, as usual, faster but has a much higher AED. The DE program is faster in all tests, but it never has a lower AED. It comes closest in Test 50 with a scaling factor of 0.4, a crossover constant of 0.8, and 12 iterations. (See Table 5.)

Table 5: Test Set 5

Test Set: 5
Data File: DATA1.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 203,820
Starting y Coordinate: -767,910
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
41	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.9	0.5	10	2.67	6.15 e +4 / 19%
42	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.3	10	2.72	1.54 e +5 / 48%
43	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.28	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.3	10	2.65	4.76 e +4 / 15%
44	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.3	0.3	10	2.69	1.08 e +5 / 34%
45	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.19	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.5	10	2.61	1.04 e +4 / 3%
46	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.5	10	2.65	1.10 e +5 / 35%
47	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.17	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.6	10	2.68	1.05 e +4 / 3%
48	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.13	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.8	10	2.55	5.95 e +3 / 2%
49	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.12	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.9	10	2.66	6.07 e +3 / 2%
50	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.35	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.4	0.8	12	2.85	3.23 e +3 / 1%

6.6 Test Set 6

The simplex program is off on the baseline run, Test 51. The DE program is closer, and faster, as usual. The second test, Test 52, with scaling factor of 0.5 and crossover constant of 0.3, has the lowest AED for the DE program while still running faster than the simplex program. Lowering and raising the scaling factor and raising the crossover constant did not improve the AED. In Test 59, the DE program gets a very good AED, but is slower (due to 15 iterations) than the simplex program. (See Table 6.)

Table 6: Test Set 6

Test Set: 6
Data File: DATA1.M
Number of Monte Carlo runs: 10
Starting x Coordinate: -140,840
Starting y Coordinate: 534,870
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
51	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.27	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.9	0.5	10	2.69	1.42 e +4 / 4%
52	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.19	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	10	2.67	1.09 e +4 / 3%
53	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.11	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.4	0.3	10	2.64	1.61 e +5 / 51%
54	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.4	0.5	10	2.72	2.76 e +4 / 9%
55	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.20	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.5	10	2.61	2.12 e +4 / 7%
56	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.6	0.3	10	2.61	1.54 e +5 / 48%
57	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.16	1.64 e +5 / 52%
	deloc1.m	dec95	10	1.1	0.3	10	2.64	1.64 e +5 / 52%
58	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.25	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	13	2.98	1.06 e +4 / 3%
59	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.22	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	15	3.26	8.13 e +3 / 3%
60	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.08	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	14	3.04	1.06 e +4 / 3%

6.7 Test Set 7

The simplex program has a very good AED in this test set. The DE program is faster, but with a higher AED for the baseline run. In Test 62, the scaling factor is set to 0.5 and the crossover constant is set to 0.3. These are usually good values but still produce a higher AED in this Test Set. Raising and lowering both the crossover constant and the scaling factor failed to produce a lower AED. Raising the number of iterations in Test 68 does not produce a lower AED. However, in Test 67, lowering the number of iterations of the DE simulator produces an AED and an elapsed time that is lower than the simplex program.

Table 7: Test Set 7

Test Set: 7
Data File: DATA2.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 20,100
Starting y Coordinate: -67,900
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
61	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.15	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.9	0.5	10	2.60	6.25 e +3 / 2%
62	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.06	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.3	10	2.60	2.09 e +3 / .7%
63	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.10	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.4	0.3	10	2.63	3.22 e +3 / 1%
64	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.08	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.4	10	2.60	2.56 e +3 / .8%
65	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.20	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.6	0.3	10	2.63	2.89 e +3 / .9%
66	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.08	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.2	10	2.65	2.75 e +3 / .9%
67	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.07	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.3	8	2.45	1.85 e +3 / .6%
68	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.07	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.3	12	2.94	2.26 e +3 / .7%
69	Nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.13	2.03 e +3 / .6%
	deloc2.m	dec95	10	1.1	0.3	10	2.91	7.29 e +3 / 2%
70	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.05	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.8	0.3	10	2.71	2.57 e +3 / .8%

6.8 Test Set 8

The baseline run of the simplex program has a tight grouping, but is off. The DE baseline run is faster and has a tight grouping, but has an even higher AED. Test 72 sets the scaling factor to 0.5 and the crossover constant to 0.3, usually good values. These settings produce an AED lower than the simplex program's, but still high. Setting the parameters to the other usually good setting of F = 0.5 and CR = 0.5 produce a lower AED, but still not a good one. Setting the scaling factor to 0.4 and the crossover constant to 0.5 produce the best results for this test set and a fairly good AED. (See Table 8.)

Table 8: Test Set 8

Test Set: 8
Data File: DATA2.M
Number of Monte Carlo runs: 10
Starting x Coordinate: -254,200
Starting y Coordinate: 1,016,000
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
71	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.9	0.5	10	2.83	1.88 e +5 / 59%
72	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.56 e +5 / 49%
	deloc2.m	dec95	10	05	0.3	10	2.86	4.71 e +4 / 15%
73	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.3	10	2.82	9.69 e +4 / 30%
74	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.35	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.5	05	10	2.82	2.05 e +4 / 6%
75	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.34	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.5	0.6	10	2.86	1.59 e +5 / 50%
76	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.5	10	2.85	6.00 e +3 / 2%
77	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.31	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.4	10	2.59	1.98 e +4 / 6%
78	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.3	0.5	10	2.63	1.43 e +5 / 45%
79	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.27	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.6	0.5	10	2.72	1.08 e +5 / 34%
80	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.29	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.8	0.5	10	2.68	1.77 e +5 / 55%

6.9 Test Set 9

The simplex method has a mediocre AED for this test set due to some of the points being way off. The DE program is faster and has a tight grouping, but still has an even higher AED. Test 82, with the scaling factor set to 0.5 and the crossover constant at 0.3, produces the best DE run of this test set. These usually good values provide only a fair AED, but one that is lower than the simplex program's. Raising and lowering both F and CR failed to yield a lower number. (See Table 9.)

Table 9: Test Set 9

Test Set: 9
Data File: DATA2.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 265,200
Starting y Coordinate: -1,058,300
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
81	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.14	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.9	0.5	10	2.57	8.75 e +4 / 27%
82	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.05	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.5	0.3	10	2.60	1.91 e +4 / 6%
83	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.10	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.5	0.4	10	2.63	2.53 e +5 / 79%
84	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.11	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.4	0.3	10	2.66	1.67 e +5 / 52%
85	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.14	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.5	0.5	10	2.63	1.45 e +5 / 45%
86	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.20	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.4	0.5	10	2.74	2.14 e +5 / 67%
87	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.15	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.5	0.2	10	2.61	1.42 e +5 / 44%
88	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.34	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.6	0.3	10	2.61	1.62 e +5 / 51%
89	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	2.95	7.94 e +4 / 25%
	deloc2.m	dec95	10	1.1	0.3	10	2.64	1.21 e +5 / 38%
90	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.11	7.94 e +4 / 25%
	deloc2.m	dec95	10	1.1	0.5	10	2.67	3.18 e +5 / 99%

6.10 Test Set 10

The simplex program has a very good AED in this test set. The DE program has a tight grouping and is faster, but is way off. The usually good combination of F = 0.5 and CR = 0.3 yields an AED that is lower than the baseline number, but not the simplex's number. Setting the scaling factor to 0.6 and the crossover constant to 0.5 produces the best run of the test set for the DE program in Test 97. This test's AED is still higher than the simplex program's. Further manipulations, including raising the number of iterations, fail to provide a better AED.

Table 10: Test Set 10

Test Set: 10
Data File: DATA3.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 164,800
Starting y Coordinate: -598,700
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
91	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.20	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.9	0.5	10	2.70	1.63 e +5 / 50%
92	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.18	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.3	10	2.61	4.14 e +4 / 13%
93	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.17	2.19e +3 / .7%
	deloc3.m	dec95	10	0.4	0.3	10	2.67	1.13 e +5 / 35%
94	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.15	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.3	10	2.69	1.56 e +5 / 48%
95	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.64	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.4	10	2.64	1.79 e +5 / 55%
96	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.17	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.2	10	2.65	1.52 e +5 / 47%
97	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.12	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.5	10	2.69	7.23 e +3 / 2%
98	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.32	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.7	0.5	10	2.69	1.68 e +5 / 52%
99	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.23	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.5	14	3.26	7.23 e +3 / 2%
100	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.13	2.19 e +3 / .7%
	deloc3.m	dec95	11	0.6	0.5	12	3.24	1.50 e +5 / 46%

6.11 Test Set 11

The simplex program has a tight grouping and a high AED for this test set. The DE program is faster, is tightly grouped, and has a lower, but not a really good AED. (See Table 11.) The best AED achieved by the DE method for this Test Set is during Test 102. The usually good settings of F = 0.5 and CR = 0.3 yield a low AED. Trying higher and lower values for both the scaling factor and the crossover constant did not do any better than Test 102.

Table 11: Test Set 11

Test Set: 11
Data File: DATA3.M
Number of Monte Carlo runs: 10
Starting x Coordinate: -69,200
Starting y Coordinate: 250,800
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
101	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.41	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.9	0.5	10	2.68	1.38 e +4 / 4%
102	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.5	0.3	10	2.61	3.82 e +3 / 1%
103	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.25	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.4	0.3	10	2.64	6.21 e +3 / 2%
104	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.47	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.6	0.3	10	2.68	2.25 e +4 / 7%
105	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.5	0.4	10	2.67	2.07 e +4 / 6%
106	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.34	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.5	0.2	10	2.64	1.20 e +5 / 37%
107	nmloc3.m	nmc275	n/a	n/a	N/a	n/a	3.33	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.5	0.5	10	2.69	1.70 e +5 / 52%
108	nmloc3.m	nmc275	n/a	n/a	N/a	n/a	3.34	1.70 e +5 / 52%
	deloc3.m	dec95	10	1.1	0.3	10	2.99	2.39 e +4 / 7%
109	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.53	1.70 e +5 / 52%
	deloc3.m	dec95	10	1.1	0.4	10	2.63	1.67 e +4 / 5%
110	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.34	1.70 e +5 / 52%
	deloc3.m	dec95	10	1.1	0.5	10	2.68	1.75 e +5 / 54%

6.12 Test Set 12

In this test set, the simplex program has a good, low AED with tight grouping. The DE program is faster, tighter, but with a higher AED. Setting the parameters to the usually good F = 0.5, CR = 0.3, and F = 0.5, CR = 0.5 produced better results than the baseline, but did not beat the simplex program. Other parameter manipulation also failed. Raising the number of iterations to 15 produced the best AED for the DE program in Test 120. This AED was just a little faster than the simplex program and still had a higher AED. (See Table 12.)

Table 12: Test Set 12

Test Set: 12
Data File: DATA3.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 292,700
Starting y Coordinate: -1,083,600
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
111	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.35	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.9	0.5	10	2.66	7.07 e +4 / 22%
112	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.21	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.3	10	2.66	5.77 e +4 / 18%
113	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.26	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.3	10	2.71	1.67 e +5 / 51%
114	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.29	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.4	0.3	10	2.70	1.91 e +5 / 59%
115	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.24	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.4	10	2.70	2.12 e +5 / 65%
116	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.45	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.2	10	2.67	1.79 e +5 / 55%
117	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.33	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.5	10	2.62	2.87 e +4 / 9%
118	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.33	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.5	12	2.79	2.98 e +4 / 9%
119	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.31	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	05	13	2.89	1.00 e +5 / 31%
120	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.21	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.5	15	3.12	7.71 e +3 / 2%

6.13 Test Set 13

Test Set 13 reran Tests 3, 7, and 10 in order to produce Table 15 below which compares the results of running the data from each test set with a population of 10, a scaling factor of 0.5, a crossover constant of 0.5, and 10 iterations. Table 14 below compares the results of running the data from each test set with a population of 10, a scaling factor of 0.5, a crossover constant of 0.3, and 10 iterations. All of this data was already available in other tables, so no additional tests were necessary. (See Table 13.)

Table 13: Test Set 13

Test Set 13								
Data from Test Set 3 Data File: DATA.M Number of Monte Carlo runs: 10 Starting x Coordinate: -253,800 Starting y Coordinate: 969,680 SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
121	Nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.33	1.62 e +5 / 51%
	Deloc.m	dec95	10	0.5	0.5	10	2.50	2.23 e +4 / 7%
Data from Test Set 7 Data File: DATA2.M Number of Monte Carlo runs: 10 Starting x Coordinate: 20,100 Starting y Coordinate: -67,900 SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
122	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.24	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.5	10	2.66	2.07 e +3 / .6%
Data from Test Set 10 Data File: DATA3.M Number of Monte Carlo runs: 10 Starting x Coordinate: 164,800 Starting y Coordinate: -598,700 SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
123	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.20	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.5	10	2.65	6.69 e +4 / 21%

In Test Sets 2, 3, 6, 9, and 11, setting the population size to 10, the scaling factor to 0.5, the crossover constant to 0.3, and the number of iterations to 10 produces the best result of the test set for the DE method and produces a lower AED than the simplex method. In Test Sets 1 and 8 these parameters still outperform the simplex method even though they are not the best values the DE program achieves for the test set. In Test Set 7, the DE AED is very close to the simplex number. (See Tables 14 and 15.)

Table 14: Comparison Tests

Comparison with F = 0.5 and CR = 0.3

Data from all Test Sets
Data File: All
Number of Monte Carlo runs: 10
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
10	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.3	10	2.82	3.32 e +4 / 10%
14	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.25	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.3	10	2.63	1.58 e +3 / .5%
22	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.3	10	2.48	3.51 e +4 / 11%
32	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.3	10	2.86	1.44 e +4 / 5%
42	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.3	10	2.72	1.54 e +5 / 48%
52	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.19	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	10	2.67	1.09 e +4 / 3%
62	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.06	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.3	10	2.60	2.09 e +3 / .7%
72	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.32	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.5	0.3	10	2.86	4.71 e +4 / 15%
82	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.05	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.5	0.3	10	2.60	1.91 e +4 / 6%
92	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.18	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.3	10	2.61	4.14 e +4 / 13%
102	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.5	0.3	10	2.61	3.82 e +3 / 1%
112	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.21	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.3	10	2.66	5.77 e +4 / 18%

In Test Set 1 setting the population size to 10, the scaling factor to 0.5, the crossover constant to 0.5, and the number of iterations to 10 produces the best result of the test set for the DE method and produces a lower AED than the simplex method. In Test Sets 3, 6, 8, and 11 these parameters still equal or outperform the simplex method even though they are not the best values the DE program achieves for the test set. In Test Set 7, the DE AED is very close to the simplex number.

Table 15: Comparison Tests

Comparison with F = 0.5 and CR = 0.5

Data from all Test Sets
Data File: All
Number of Monte Carlo runs: 10
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
9	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.28	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.5	10	2.66	2.10 e +4 / 7%
12	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.05	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.5	10	2.76	2.30 e +4 / 7%
121	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.33	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.5	10	2.50	2.23 e +4 / 7%
33	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.04	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.5	10	2.66	5.77 e +4 / 18%
46	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.5	0.5	10	2.65	1.10 e +5 / 35%
55	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.20	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.5	10	2.61	2.12 e +4 / 7%
122	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.24	2.03 e +3 / .6%
	deloc2.m	dec95	10	0.5	0.5	10	2.66	2.07 e +3 / .6%
74	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.35	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.5	0.5	10	2.82	2.05 e +4 / 6%
85	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.14	7.94 e +4 / 25%
	deloc2.m	dec95	10	0.5	0.5	10	2.63	1.45 e +5 / 45%
123	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.20	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.5	10	2.65	6.69 e +4 / 21%
107	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.33	1.70 e +5 / 52%
	deloc3.m	dec95	10	0.5	0.5	10	2.69	1.70 e +5 / 52%
117	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.33	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.5	0.5	10	2.62	2.87 e +4 / 9%

6.14 Test Set 14

In the 10 Monte Carlo run test, Test 9, the simplex program took about 23 percent longer to execute and had an AED about 7.7 times greater than the DE program. In the 5 Monte Carlo run test, Test 124, the simplex program took about 17 percent longer to execute and had an AED about 7.6 times greater than the DE program. In the 20 Monte Carlo run test, Test 125, the simplex program took about 17 percent longer to execute and had an AED about 7.8 times greater than the DE program. In the 50 Monte Carlo run test, Test 126, the simplex program took about 50 percent longer to execute and had an AED about 7.9 times greater than the DE program. (See Table 16.)

Table 16: Test Set 14 Part A

Test Set 14 Part A								
Data File: DATA.M Starting x Coordinate: -247,010 Starting y Coordinate: 938,510 Data from Test 9 included for reference. SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Number of Monte Carlo runs: 5								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
124	nmloc.m	nmc275	n/a	n/a	n/a	n/a	2.41	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.5	10	2.05	2.13 e +4 / 7%
Number of Monte Carlo runs: 20								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
125	nmloc.m	nmc275	n/a	n/a	n/a	n/a	5.12	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.5	10	4.34	2.07 e +4 / 6%
Number of Monte Carlo runs: 50								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
126	nmloc.m	nmc275	n/a	n/a	n/a	n/a	10.93	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	05	10	7.28	2.04 e +4 / 6%
9	nmloc.m	nmc275	n/a	n/a	n/a	n/a	3.28	1.62 e +5 / 51%
	deloc.m	dec95	10	0.5	0.5	10	2.66	2.10 e +4 / 7%

In the 10 Monte Carlo run test, Test 52, the simplex program took about 19 percent longer to execute and had an AED about 15 times greater than the DE program. In the 5 Monte Carlo run test, Test 127, the simplex program took about 15 percent longer to execute and had an AED about 13.9 times greater than the DE program. In the 20 Monte Carlo run test, Test 128, the simplex program took 29 percent longer to execute and had an AED about 15.8 times greater than the DE program. In the 50 Monte Carlo run test, Test 129, the simplex program took about 31 percent longer to execute and had an AED about 14 times greater than the DE program. (See Table 17.)

Table 17: Test Set 14 Part B

Test Set 14 Part B								
Data File: DATA1.M Starting x Coordinate: -140,840 Starting y Coordinate: 534,870 Data from Test 52 included for reference SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Number of Monte Carlo runs: 5								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
127	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	2.36	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	10	2.04	1.18 e +4 / 4%
Number of Monte Carlo runs: 20								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
128	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	4.92	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	10	3.80	1.04 e +4 / 3%
Number of Monte Carlo runs: 50								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
129	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	9.90	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	10	7.52	1.17 e +4 / 4%
52	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.19	1.64 e +5 / 52%
	deloc1.m	dec95	10	0.5	0.3	10	2.67	1.09 e +4 / 3%

In the 10 Monte Carlo run test, Test 76, the simplex program took about 15 percent longer to execute and had an AED about 26 times greater than the DE program. In the 5 Monte Carlo run test, Test 130, the simplex program took about 13 percent longer to execute and had an AED about 26 times greater than the DE program. (See Table 18.) In the 20 Monte Carlo run test, Test 131, the simplex program took 31 percent longer to execute and had an AED about 26 times greater than the DE program. In the 50 Monte Carlo run test, Test 132, the simplex program took about 44 percent longer to execute and had an AED about 24.8 times greater than the DE program.

Table 18: Test Set 14 Part C

Test Set 14 Part C								
Data File: DATA2.M Starting x Coordinate: -254,200 Starting y Coordinate: 1,016,000 Data from Test 76 SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Number of Monte Carlo runs: 5								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
130	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	2.42	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.5	10	2.13	6.00 e +3 / 2%
Number of Monte Carlo runs: 20								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
131	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	5.07	1.57 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.5	10	3.85	6.00 e +3 / 2%
Number of Monte Carlo runs: 50								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
132	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	11.58	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.5	10	8.02	6.30 e +3 / 2%
76	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.30	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.4	0.5	10	2.85	6.00 e +3 / 2%

In the 10 Monte Carlo run test, Test 97, the simplex program took about 15 percent longer to execute and the DE program had an AED about 3.3 times greater than the simplex program. In the 5 Monte Carlo run test, Test 133, the simplex program took about 14 percent longer to execute and the DE program had an AED about 2.9 times greater than the simplex program. In the 20 Monte Carlo run test, Test 134, the simplex program took 24 percent longer to execute and had an AED about 2.8 times greater than the DE program. In the 50 Monte Carlo run test, Test 135, the simplex program took about 33 percent longer to execute and had an AED about 2.6 times greater than the DE program. (See Table 19.)

Table 19: Test Set 14 Part D

Test Set 14 Part D								
Data File: DATA3.M Starting x Coordinate: 164,800 Starting y Coordinate: -598,700 Data from Test 97 included for reference SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Number of Monte Carlo runs: 5								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
133	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	2.39	2.46 e +3 / .8%
	deloc3.m	dec95	10	0.6	0.5	10	2.08	7.23 e +3 / 2%
Number of Monte Carlo runs: 20								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
134	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	4.86	2.56 e +3 / .8%
	deloc3.m	dec95	10	0.6	0.5	10	3.89	7.23 e +3 / 2%
Number of Monte Carlo runs: 50								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
135	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	9.82	2.79 e +3 / .9%
	deloc3.m	dec95	10	0.6	0.5	10	7.34	7.23 e +3 / 2%
97	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.12	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.5	10	2.69	7.23 e +3 / 2%

6.15 Test Set 15

These tests repeat Tests 19, 44, 75, and 99 to confirm that repeating either the simplex or the DE programs with the same DATA file and input data will produce the same AED. (See Table 20.)

Table 20: Test Set 15

Test Set 15								
Repeat of Test 19 Data File: DATA.M Number of Monte Carlo runs: 10 Starting x Coordinate: 77,510 Starting y Coordinate: -305,660 Data from Test 19 included for reference SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
136	nmloc.m	nmc275	n/a	n/a	N/a	n/a	3.12	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.4	10	2.65	1.19 e +4 / 4%
19	nmloc.m	nmc275	n/a	n/a	N/a	n/a	3.09	1.89 e +3 / .6%
	deloc.m	dec95	10	0.5	0.4	10	2.67	1.19 e +4 / 4%
Repeat of Test 44 Data File: DATA1.M Number of Monte Carlo runs: 10 Starting x Coordinate: 203,820 Starting y Coordinate: -767,910 Data from Test 44 included for reference SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable Iter = Iterations								
Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
137	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.19	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.3	0.3	10	2.61	1.08 e +5 / 34%
44	nmloc1.m	nmc275	n/a	n/a	n/a	n/a	3.21	1.77 e +3 / .6%
	deloc1.m	dec95	10	0.3	0.3	10	2.69	1.08 e +5 / 34%

Table 20 - Continued

Repeat of Test 75
Data File: DATA2.M
Number of Monte Carlo runs: 10
Starting x Coordinate: -254,200
Starting y Coordinate: 1,016,000
Data from Test 75 included for reference
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
138	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.29	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.5	0.6	10	2.62	1.59 e +5 / 50%
75	nmloc2.m	nmc275	n/a	n/a	n/a	n/a	3.34	1.56 e +5 / 49%
	deloc2.m	dec95	10	0.5	0.6	10	2.86	1.59 e +5 / 50%

Repeat of Test 99
Data File: DATA3.M
Number of Monte Carlo runs: 10
Starting x Coordinate: 164,800
Starting y Coordinate: -598,700
Data from Test 99 included for reference
SF = Scaling Factor, CR = Crossover Constant, n/a = Not Applicable
Iter = Iterations

Test #	MATLAB Program	C++ DLL	Pop Size	SF	CR	Iter	Time Elapsed (secs)	Average Error Distance (meters / % of initial range to emitter)
139	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.18	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.5	14	2.94	7.23 e +3 / 2%
99	nmloc3.m	nmc275	n/a	n/a	n/a	n/a	3.23	2.19 e +3 / .7%
	deloc3.m	dec95	10	0.6	0.5	14	3.26	7.23 e +3 / 2%

7 ANALYSIS AND CONCLUSIONS

7.1 Analysis

This project is a comparison between two minimization techniques. The environment in which the two methods are tested is passive emitter location in the presence of noise. Because the measurements were limited to passive reception by a single emitter in a noisy environment, at ranges that sometimes exceed 320,000 meters, pinpoint accuracy is not a reasonable expectation. The solutions obtained by the two methods varied from within 1,000 meters of the location of the emitter to within 1 million meters of its location. A 10 Monte Carlo run with an average error within 10,000 meters was a good solution. A run with an average error within 2,000 meters was an excellent solution.

The overall results were mixed. The DE method was always the fastest method except in Tests 1 through 5, 37, 59, and 99 in which the number of iterations was higher than usual, and Test 100, which had a higher number of iterations and a higher population size. The DE method was faster and had a lower AED in comparison Test Sets 1,2,3,6,7,8,9, and 11. The simplex method was slower but had a significantly lower AED in Test Sets 4, 5, 10, and 12. The AED of the DE method was about 139 percent higher than the simplex AED in Test Set 4. In Test Set 5, the DE AED was about 82 percent higher than the simplex AED. In Test Set 10, the DE AED was about 230 percent higher than the simplex's solution AED. In the last comparison, Test Set 12, the DE AED was about 252 percent higher than the simplex AED.

The success of the DE method in the majority of the Test Sets is tempered by the fact that no one set of parameters produced the best AED in all of those test sets. In one Test Set, a population size of 10, scaling factor F of 0.5, crossover constant CR of 0.5, and number of iterations equal to 10 produce the best result. In 5 Test Sets a population of 10, F of 0.5, CR of 0.3, and 10 iterations produce the best result. In one test set the same parameters with 8 iterations produces the best result. In one test set a population of 10, F of 0.4, CR of 0.5, and 10 iterations is the best while in another the same population and iterations with F of 0.6 and CR of 0.5 yields the best result.

Because of this difference in parameters, Tables 14 and 15 were put together to look at the results of running two sets of relatively successful sets of parameters. Table 14, made up of test results from Test Sets 1 through 12, tracks the parameter set with population size of 10, F of 0.5, CR of 0.3, and 10 iterations against all 12 sets of test data. In seven of the tests, the DE method was faster than the simplex method and had a lower AED. In five of the tests, these parameters provided the best solution. In the other two, the solution was better than the simplex solution, but not the best for the Test Set. In Test Set 7, the DE AED was only about 3 percent higher than the simplex number. This set of parameters did very well in a majority of the test cases.

Table 15 is made up of test results from Test Sets 1,2,4,5,6,8,9,11,12, and 13. Test Set 13 ran the data from Test Sets 3,7, and 10 through the simulator with a population of 10, F of 0.5, CR of 0.5, and 10 iterations since these tests weren't performed as part of the original runs. This set of parameters is not as successful as the previous one. In five of the tests the DE method produces an AED lower than or equal to the simplex method. In Test Set 1, this solution is also the best for the entire test set. Test Set 7's DE AED is

once again close. It is only about three percent higher than the simplex result. This set of parameters did okay but is clearly not as powerful as the previous one.

A large number of other parameter combinations that still yield a faster time is obviously possible. It is also possible that one exists that is even more powerful than the combination of F at 0.5 and CR at 0.3. These two combinations were chosen for investigation only because they emerged from the comparison testing as promising solutions.

One of the main factors that determine the speed of both methods is obviously the number of Monte Carlo runs that the user inputs into the MATLAB simulator. In order to investigate the effects of lowering and raising the number of Monte Carlo simulations on the elapsed time and AED, Test Set 14 was run. Tests lowering the number of Monte Carlo runs to five while using the rest of the data from previously run tests were conducted. Then similar tests were run with the number of Monte Carlo runs raised to first 20, and then 50. These results were displayed beside the original 10 Monte Carlo run tests in Tables 16 through 19.

In all cases, the relative positions of the methods from the original tests were preserved. In no case was a method faster or more accurate than the other with 5, 20, or 50 Monte Carlo runs that was not faster or more accurate with 10. In general, the difference in time elapsed tended to decrease with fewer Monte Carlo runs and increase with more Monte Carlo runs. The difference in AED varied in different ways for different tests, but never by very much. Running greater or fewer numbers of Monte Carlo simulations has no real impact on the comparison of the two methods.

The same seed is used for the MATLAB random number generator for both versions of the simulator. This causes identical noise to be generated for both versions. It also causes the runs to be repeatable by generating the same random sequence when the same input data and starting data is supplied. Test Set 15 confirms that the AED results are repeatable for both the simplex and the DE simulators with each of the input data files.

7.2 Conclusions

The Nelder-Mead simplex minimization method is a time-tested, reliable way to find a function's minimum. The original MATLAB passive emitter simulator used the fmins function to minimize the SSE. This function implements the Nelder-Mead simplex method in the MATLAB language. As part of this project, the Nelder-Mead simplex technique was moved to an external dll written in C++. The simulators based on this method, nmloc.m, nmloc1.m, nmloc2.m, and nmloc3.m all produced fast and generally good solutions within the limitations of the passive, noisy, scenario.

Price and Storn's DE minimization method is based on an artificial intelligence technique called genetic algorithms. This makes the technique very non-deterministic. The fact that DE uses actual real number values for its vectors makes it faster than regular genetic algorithms because no translation back and forth from a symbol alphabet is necessary. It also uses search increments based on the actual search area in use. Conventional genetic algorithms usually swap symbols in their alphabet causing large movements inside the search area. This swapping also is arbitrary and not adjusted to the topography of the

area under search. The simulators based on this method, deloc.m, deloc1.m, deloc2.m, and deloc3.m all produced the fastest solutions. In the majority of the comparison tests, they also produced the best solutions.

Differential Evolution is a very promising tool for this application. Using passive measurements in a noisy environment, the DE simulators were faster than the simplex ones. Their accuracy overall was as good or better than the conventional simplex method. There are several avenues to provide good follow-on research. The main area of interest would be DE's accuracy. The exact parameter combinations that provide the most accurate solutions would provide a good subject for a follow-on study. A project that focused on minimizing DE's AED instead of maximizing speed might show exactly how accurate DE can be in a noisy environment. Since the noise will have an effect on the function of the SSE landscape, this project could also investigate exactly how the level of noise affects the accuracy. A study of the effects of various sensor flight paths on DE's accuracy would also be interesting. Price and Storn have developed alternative crossover techniques that can be seen and downloaded at the internet address

www.ICSI.Berkeley.edu/~storn/code.html.

These alternatives are also an area that would provide good follow-on projects.

8 TEST OUTPUT EXAMPLES

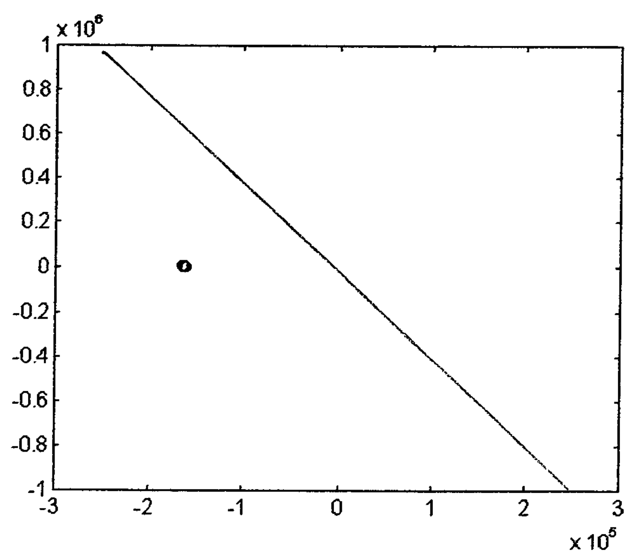
This section includes test run logs and result plots for a test from each comparison test set.

8.1 Test 2 Output

8.1.1 Test 2 Simplex Log

```
nmloc

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
         0         0         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=     0.000      0.000      0.000
xmtr frequency carrier f0= 9.000000000 Ghz
xmtr frequency drift fd=     0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=      0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000     10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-     0.0m
samples @   0.200 sec from t=     0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    356629.8 m
ellipse angle=  104.696 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2702      1020417
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1259       475505


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-247010,938510]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

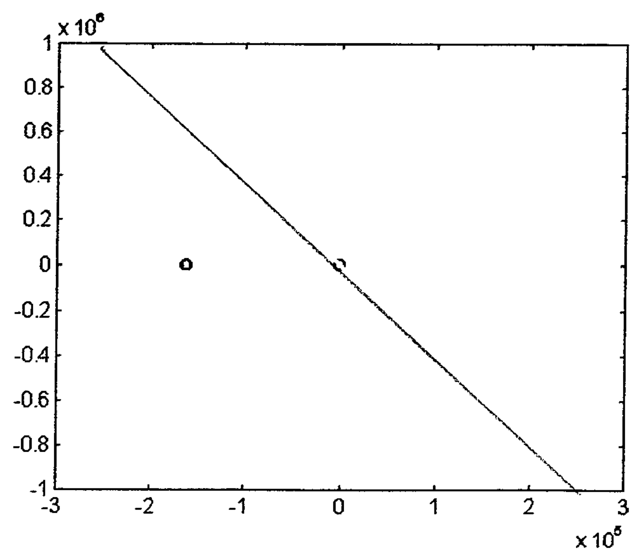
```
Output points are:
xye =
  Columns 1 through 3
   -1.613058816561902e+005   -1.626890549389913e+005   -1.631073104112395e+005
    1.991050691160579e+003   -1.398656667094303e+003   -1.572493258624310e+002
  Columns 4 through 6
   -1.614607968766703e+005   -1.602755010889106e+005   -1.635913808505362e+005
   -1.908057051477455e+003   -3.763477601501298e+002    2.100313466255770e+003
  Columns 7 through 9
   -1.621191508130038e+005   -1.630579401878840e+005   -1.624179713127351e+005
    4.965277739482053e+002   -8.497049786687361e+002    1.063033078362802e+002
  Column 10
   -1.631633980550578e+005
   -1.041569241368311e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.613181692796432e+005    1.626950670346662e+005    1.631073862120870e+005
  Columns 4 through 6
    1.614720706802296e+005    1.602759429450907e+005    1.636048630244276e+005
  Columns 7 through 9
    1.621199111773744e+005    1.630601541053679e+005    1.624180061007329e+005
  Column 10
    1.631667224998952e+005
Average error distance is:
ans =
    1.623238293059514e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.000004557894194e+009    9.000004571107128e+009    9.000004590475630e+009
  Columns 4 through 6
    9.000004535394526e+009    9.000004514516407e+009    9.000004619205153e+009
  Columns 7 through 9
    9.000004569137020e+009    9.000004584662680e+009    9.000004574348686e+009
  Column 10
    9.000004585775795e+009
return

exit

 22252 flops.
```



8.1.2 Test 2 Differential Evolution Log

```
deloc

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
         0         0         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=    0.000      0.000      0.000
xmtr frequency carrier f0= 9.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000      0.000     10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-     0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift), CEP=    356629.8 m
ellipse angle=  104.696 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2702      1020417
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1259       475505


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 50
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-247010,938510]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -1.609136925876579e+005    9.147578826383428e+002   -1.631176779231157e+005
    1.240250628683563e+003   -2.547207118151866e+003   -2.167299799286361e+002
  Columns 4 through 6
   -5.055800283302406e+002   -1.602999108158804e+005    1.359609006614725e+003
   -4.658413108598725e+003   -2.141044253374799e+003    1.175421667023102e+003
  Columns 7 through 9
   -1.611087702367936e+005    1.319366796146205e+003    8.657623391099421e+002
   -8.146751823346219e+002   -1.405915826863722e+003   -4.194659968253618e+002
  Column 10
   -1.632891096897991e+005
   -3.354251448531724e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.609184721646872e+005    2.706482234675210e+003    1.631178219046390e+005
  Columns 4 through 6
    4.685768224678941e+003    1.603142085969740e+005    1.797262570181454e+003
  Columns 7 through 9
    1.611108299986834e+005    1.928037358299627e+003    9.620271047708650e+002
  Column 10
    1.633235572294065e+005
Average error distance is:
ans =
    8.208644673869963e+004
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.000004542318163e+009    8.999999993651260e+009    9.000004590334736e+009
  Columns 4 through 6
    9.000000045056068e+009    9.000004503314394e+009    8.999999955951443e+009
  Columns 7 through 9
    9.000004533503199e+009    8.999999975263802e+009    8.999999980182220e+009
  Column 10
    9.000004573157421e+009

return

exit

 22398 flops.
```

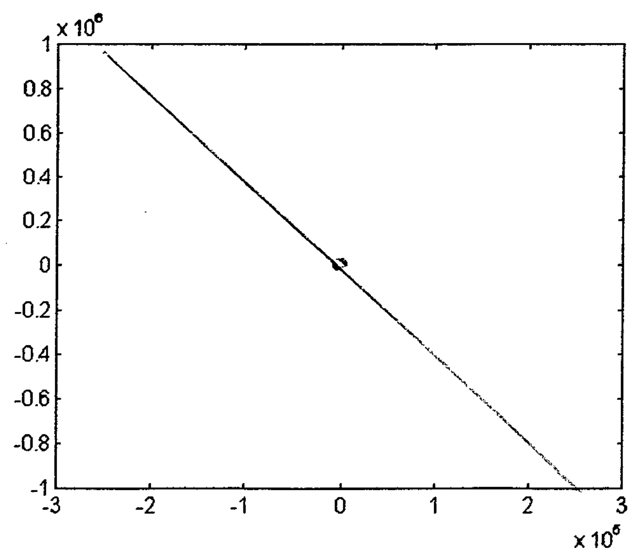


8.2 Test 14 Output

8.2.1 Test 14 Simplex Log

```
nmloc

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
         0         0         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=     0.000     0.000     0.000
xmtr frequency carrier f0= 9.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=      0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000     10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=    4.8500sec and
varies over  3200.0m +/-     0.0m
samples @   0.200 sec from t=     0.000 to t=    10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=     356629.8 m
ellipse angle=  104.696 d ccw from x,  mean freq.dev=     1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2702      1020417
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1259       475505


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[77510,-305660]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

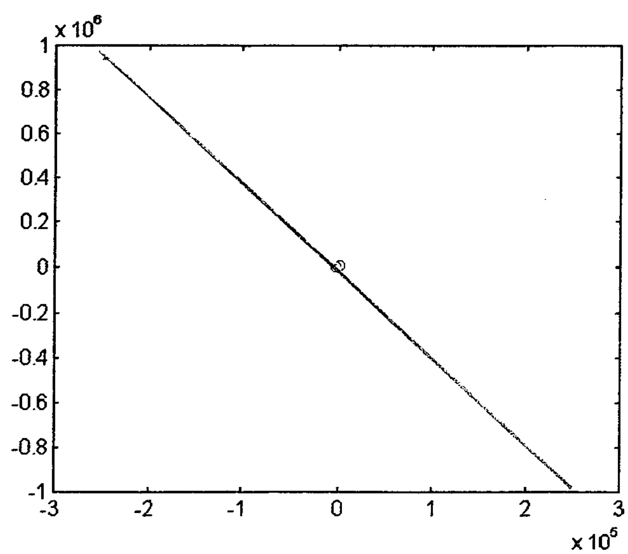
```
Output points are:
xye =
  Columns 1 through 3
   -6.797621861250396e+002    7.526753331385296e+002    1.180420272792195e+003
    8.844347837845773e+002   -2.450106273055583e+003   -1.200103256131274e+003
  Columns 4 through 6
   -4.959596119845550e+002   -1.731602435049051e+003    1.648725831099286e+003
   -2.967038903054429e+003   -1.494826547088656e+003    1.015851430924509e+003
  Columns 7 through 9
    1.656752144073194e+002    1.099600469026475e+003    4.790085547727310e+002
   -5.602479147064789e+002   -1.966498595779825e+003   -9.371133007599370e+002
  Column 10
    1.201040219831262e+003
   -2.147275009425297e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.115482638346992e+003    2.563111567291115e+003    1.683341868366520e+003
  Columns 4 through 6
    3.008204745185789e+003    2.287564949667833e+003    1.936556478867942e+003
  Columns 7 through 9
    5.842311208775764e+002    2.253050802509182e+003    1.052440275743305e+003
  Column 10
    2.460342979292671e+003
Average error distance is:
ans =
    1.894432742614892e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.000000011781397e+009    8.999999997216190e+009    8.999999977181679e+009
  Columns 4 through 6
    9.000000033399137e+009    9.000000055900654e+009    8.999999949470839e+009
  Columns 7 through 9
    8.999999999526537e+009    8.999999984903320e+009    8.999999993932161e+009
  Column 10
    8.999999983178770e+009
return

exit

 22398 flops.
```



8.2.2 Test 14 Differential Evolution Log

```
deloc

sinmod =
  1.0e+005 *
         0          0          0
         0     0.0000          0
    0.0001          0          0
         0          0          0
   -0.8282     3.0910     0.0320
         0          0     0.0001
    0.0001          0     0.0030
         0     0.0000     0.0001
         0          0          0
         0          0          0
         0          0          0
         0          0     0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=     0.000      0.000      0.000
xmtr frequency carrier f0= 9.000000000 Ghz
xmtr frequency drift fd=     0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=      0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000     10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=    4.8500sec and
varies over   3200.0m +/-     0.0m
samples @    0.200 sec from t=     0.000 to t=    10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=     356629.8 m
ellipse angle=  104.696 d ccw from x,  mean freq.dev=     1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2702      1020417
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1259       475505


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5 .3
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[77510,-305660]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -3.804519195109606e+001    -3.804519195109606e+001    -3.804519195109606e+001
   -1.269624736905098e+003    -1.269624736905098e+003    -1.269624736905098e+003
  Columns 4 through 6
   -3.804519195109606e+001    -3.804519195109606e+001     2.839258118625730e+003
   -1.269624736905098e+003    -1.269624736905098e+003     3.301553989201784e+003
  Columns 7 through 9
   -3.804519195109606e+001    -3.804519195109606e+001    -3.804519195109606e+001
   -1.269624736905098e+003    -1.269624736905098e+003    -1.269624736905098e+003
  Column 10
   -3.804519195109606e+001
   -1.269624736905098e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.270194634373778e+003     1.270194634373778e+003     1.270194634373778e+003
  Columns 4 through 6
    1.270194634373778e+003     1.270194634373778e+003     4.354497147524194e+003
  Columns 7 through 9
    1.270194634373778e+003     1.270194634373778e+003     1.270194634373778e+003
  Column 10
    1.270194634373778e+003
Average error distance is:
ans =
    1.578624885688820e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.000000009727570e+009     9.000000009806709e+009     9.000000009612576e+009
  Columns 4 through 6
    9.000000009809015e+009     9.000000009823082e+009     8.999999901713190e+009
  Columns 7 through 9
    9.000000009771637e+009     9.000000009898727e+009     9.000000009800276e+009
  Column 10
    9.000000009572948e+009

return

exit

 22398 flops.
```

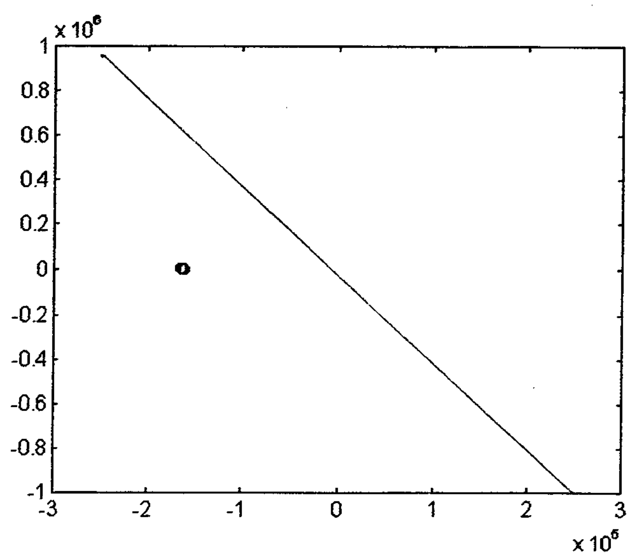


8.3 Test 26 Output

8.3.1 Test 26 Simplex Log

```
nmloc

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
         0         0         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=     0.000     0.000     0.000
xmtr frequency carrier f0= 9.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift), CEP=    356629.8 m
ellipse angle=  104.696 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2702     1020417
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1259      475505

return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-253800,969680]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

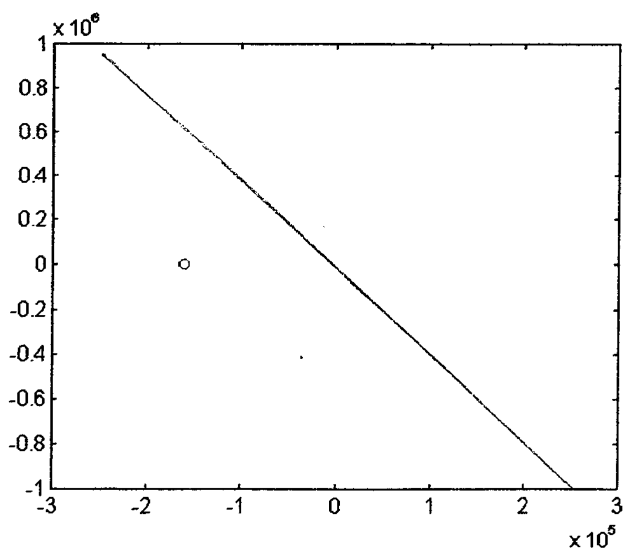
```
Output points are:
xye =
  Columns 1 through 3
   -1.613065207150858e+005   -1.626924135744568e+005   -1.631085684767315e+005
    1.996663958706520e+003   -1.402448754442444e+003   -1.532460440739621e+002
  Columns 4 through 6
   -1.614579149933846e+005   -1.602733401174066e+005   -1.635894047296413e+005
   -1.911345594660430e+003   -3.744780062254366e+002    2.102922171501889e+003
  Columns 7 through 9
   -1.621186699267002e+005   -1.630569293596504e+005   -1.624193548766044e+005
    4.964638688341854e+002   -8.519242462500961e+002    1.020864053024430e+002
  Column 10
   -1.631633442878817e+005
   -1.038360920017934e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.613188776683324e+005    1.626984581893478e+005    1.631086404666492e+005
  Columns 4 through 6
    1.614692278918594e+005    1.602737775999775e+005    1.636029205774083e+005
  Columns 7 through 9
    1.621194300976148e+005    1.630591548706155e+005    1.624193869590897e+005
  Column 10
    1.631666482851383e+005
Average error distance is:
ans =
    1.623236522606033e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.000004557949966e+009    9.000004571169159e+009    9.000004590536526e+009
  Columns 4 through 6
    9.000004535296562e+009    9.000004514471870e+009    9.000004619171423e+009
  Columns 7 through 9
    9.000004569123888e+009    9.000004584620796e+009    9.000004574355980e+009
  Column 10
    9.000004585796581e+009

exit

 22398 flops.
```



8.3.2 Test 26 Differential Evolution Log

```
deloc

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
         0         0         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=    0.000     0.000     0.000
xmtr frequency carrier f0= 9.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=    0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    356629.8 m
ellipse angle=  104.696 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
       2702      1020417
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
       1259       475505


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5 .9
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-253800,969680]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -1.594648733255267e+005   -1.594648733255267e+005   -1.594648733255267e+005
   -6.030225677788258e+002   -6.030225677788258e+002   -6.030225677788258e+002
  Columns 4 through 6
   -1.594648733255267e+005   -1.594648733255267e+005   -1.594648733255267e+005
   -6.030225677788258e+002   -6.030225677788258e+002   -6.030225677788258e+002
  Columns 7 through 9
   -1.594648733255267e+005   -1.594648733255267e+005   -1.594648733255267e+005
   -6.030225677788258e+002   -6.030225677788258e+002   -6.030225677788258e+002
  Column 10
   -1.594648733255267e+005
   -6.030225677788258e+002
Output error distances are:
dist =
  Columns 1 through 3
    1.594660134979976e+005    1.594660134979976e+005    1.594660134979976e+005
  Columns 4 through 6
    1.594660134979976e+005    1.594660134979976e+005    1.594660134979976e+005
  Columns 7 through 9
    1.594660134979976e+005    1.594660134979976e+005    1.594660134979976e+005
  Column 10
    1.594660134979976e+005
Average error distance is:
ans =
    1.594660134979976e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.000004491445633e+009    9.000004491524771e+009    9.000004491330633e+009
  Columns 4 through 6
    9.000004491527077e+009    9.000004491541138e+009    9.000004491471714e+009
  Columns 7 through 9
    9.000004491489695e+009    9.000004491616789e+009    9.000004491518339e+009
  Column 10
    9.000004491291010e+009
return

exit

 22398 flops.
```

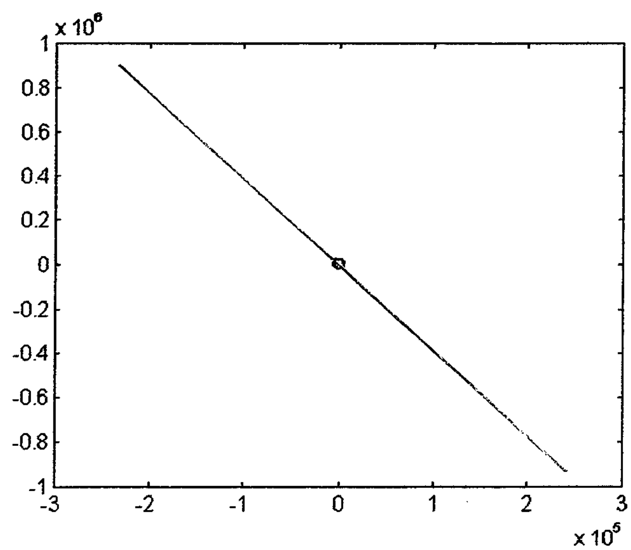


8.4 Test 34 Output

8.4.1 Test 34 Simplex Log

```
nmloc1

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0100    0.0200         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 1000.000  2000.000     0.000
xmtr frequency carrier f0= 9.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    328867.4 m
ellipse angle=  104.961 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2502      940981
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1166      438488


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[72770,-281540]
nrun =    1
nrun =    2
nrun =    3
nrun =    4
nrun =    5
nrun =    6
nrun =    7
nrun =    8
nrun =    9
nrun =   10
```

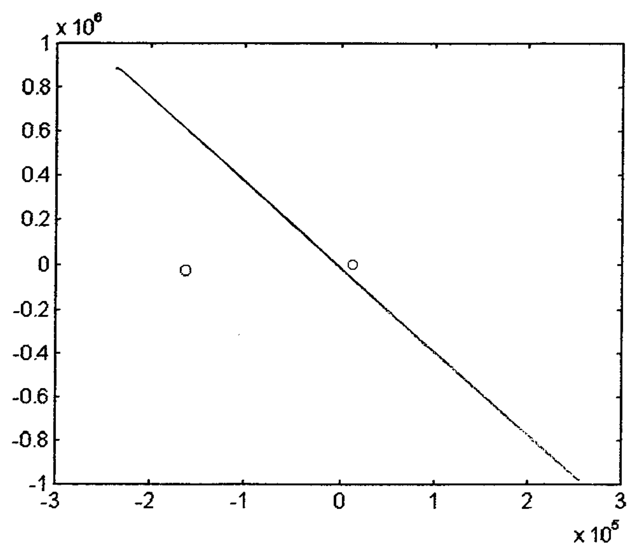
```
Output points are:
xye =
  Columns 1 through 3
    3.674182095742280e+002    1.713678677316760e+003    2.101568631569007e+003
    2.833400318262107e+003   -2.977459754536312e+002    8.896219306812179e+002
  Columns 4 through 6
    5.631182751465145e+002   -5.889011085920056e+002    2.519323018431667e+003
   -7.862975718118655e+002    5.955453055001942e+002    2.961690905983175e+003
  Columns 7 through 9
    1.160235163702712e+003    2.033582274958051e+003    1.448238094009426e+003
    1.479238251695839e+003    1.660157873361584e+002    1.118036179157422e+003
  Column 10
    2.133053916626598e+003
   -1.251455443510964e+001
Output error distances are:
dist =
  Columns 1 through 3
    1.046286677759808e+003    2.406028641178230e+003    1.564094916199436e+003
  Columns 4 through 6
    2.820340369564577e+003    2.120636631247194e+003    1.798107847985502e+003
  Columns 7 through 9
    5.448560417061017e+002    2.105181800084656e+003    9.893318807136672e+002
  Column 10
    2.309551040742772e+003
Average error distance is:
ans =
    1.770441584718195e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.500000011410542e+009    9.499999997335422e+009    9.499999977534366e+009
  Columns 4 through 6
    9.500000032799174e+009    9.500000054738274e+009    9.499999950392560e+009
  Columns 7 through 9
    9.499999999432652e+009    9.499999985120810e+009    9.499999994147694e+009
  Column 10
    9.499999983375670e+009
return

exit

 22398 flops.
```



8.4.2 Test 34 Differential Evolution Log

```
deloc1

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0100    0.0200         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 1000.000  2000.000     0.000
xmtr frequency carrier f0= 9.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=      0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000     10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=    4.8500sec and
varies over  3200.0m +/-     0.0m
samples @    0.200 sec from t=     0.000 to t=    10.000
total samples =       51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    328867.4 m
ellipse angle=  104.961 d ccw from x,  mean freq.dev=     1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2502       940981
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1166       438488


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5 .2
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[72770,-281540]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
    1.408736984968186e+004    1.408736984968186e+004    1.408736984968186e+004
   -1.161777586340904e+003   -2.827244266457856e+003   -1.161777586340904e+003
  Columns 4 through 6
    1.408736984968186e+004   -1.609661391597614e+005    1.408736984968186e+004
   -1.161777586340904e+003   -2.738753810629248e+004   -1.161777586340904e+003
  Columns 7 through 9
    1.408736984968186e+004    1.408736984968186e+004    1.408736984968186e+004
   -1.161777586340904e+003   -2.827244266457856e+003   -1.161777586340904e+003
  Column 10
    1.408736984968186e+004
   -2.827244266457856e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.346388083309747e+004    1.394924861024464e+004    1.346388083309747e+004
  Columns 4 through 6
    1.346388083309747e+004    1.646106242934154e+005    1.346388083309747e+004
  Columns 7 through 9
    1.346388083309747e+004    1.394924861024464e+004    1.346388083309747e+004
  Column 10
    1.394924861024464e+004
Average error distance is:
ans =
    2.872416551227342e+004
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.499999667301980e+009    9.499999681013224e+009    9.499999667186984e+009
  Columns 4 through 6
    9.499999667383426e+009    9.500004647724206e+009    9.499999667328064e+009
  Columns 7 through 9
    9.499999667346044e+009    9.499999681105240e+009    9.499999667374688e+009
  Column 10
    9.499999680779460e+009
return

exit

 22398 flops.
```

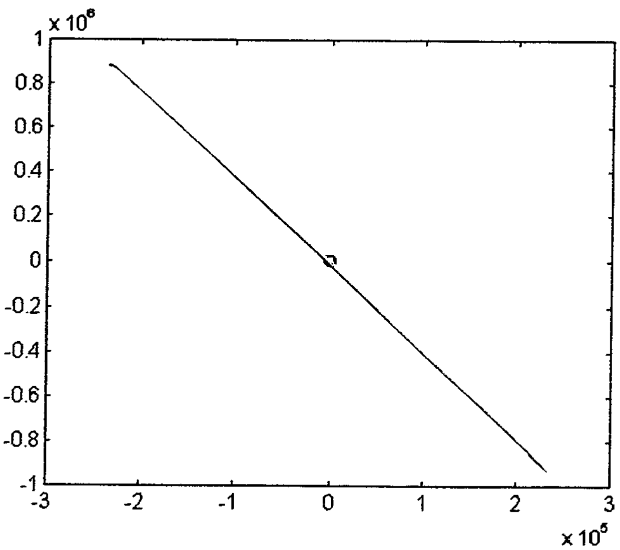


8.5 Test 45 Output

8.5.1 Test 45 Simplex Log

```
nmloc1

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0100    0.0200         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 1000.000  2000.000     0.000
xmtr frequency carrier f0= 9.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    328867.4 m
ellipse angle=  104.961 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2502      940981
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1166      438488


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[203820,-767910]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

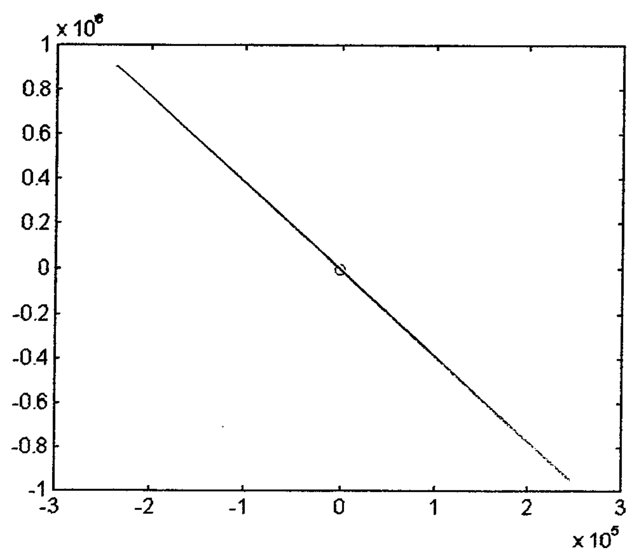
```
Output points are:
xye =
  Columns 1 through 3
    3.682960955338162e+002    1.715248323045364e+003    2.102294026538266e+003
    2.828020955533256e+003   -2.914226582271018e+002    8.828068728576886e+002
  Columns 4 through 6
    5.612129848470379e+002   -5.874888683618426e+002    2.519694487764546e+003
   -7.826897607206206e+002    5.965991591815183e+002    2.955176157971492e+003
  Columns 7 through 9
    1.158040129957764e+003    2.032514465801747e+003    1.448504962301350e+003
    1.470558625900507e+003    1.607960483772283e+002    1.114541042882725e+003
  Column 10
    2.129907245392336e+003
   -1.343656355470420e+001
Output error distances are:
dist =
  Columns 1 through 3
    1.041474207899566e+003    2.400457865128185e+003    1.569449777557714e+003
  Columns 4 through 6
    2.817072301004401e+003    2.118880559914312e+003    1.794946469647250e+003
  Columns 7 through 9
    5.525258829099557e+002    2.109207741725477e+003    9.925695270096440e+002
  Column 10
    2.308812937127881e+003
Average error distance is:
ans =
    1.770539726992438e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.500000011426116e+009    9.499999997245044e+009    9.499999977565392e+009
  Columns 4 through 6
    9.500000032825552e+009    9.500000054691194e+009    9.499999950431900e+009
  Columns 7 through 9
    9.499999999558514e+009    9.499999985189344e+009    9.499999994166372e+009
  Column 10
    9.499999983469594e+009
return

exit

 22252 flops.
```



8.5.2 Test 45 Differential Evolution Log

```
delocl

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0100    0.0200         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 1000.000  2000.000     0.000
xmtr frequency carrier f0= 9.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    328867.4 m
ellipse angle=  104.961 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
       2502      940981
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
       1166      438488


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .4
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[203820,-767910]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
    2.625229668044776e+002    2.625229668044776e+002    2.625229668044776e+002
   -8.757294885117266e+003   -8.757294885117266e+003   -8.757294885117266e+003
  Columns 4 through 6
    2.625229668044776e+002    2.625229668044776e+002    2.625229668044776e+002
   -6.652790093175608e+003   -6.652790093175608e+003   -8.757294885117266e+003
  Columns 7 through 9
    2.625229668044776e+002    2.625229668044776e+002    2.625229668044776e+002
   -8.757294885117266e+003   -8.757294885117266e+003   -8.757294885117266e+003
  Column 10
    2.625229668044776e+002
   -8.757294885117266e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.078254448726556e+004    1.078254448726556e+004    1.078254448726556e+004
  Columns 4 through 6
    8.684160798318329e+003    8.684160798318329e+003    1.078254448726556e+004
  Columns 7 through 9
    1.078254448726556e+004    1.078254448726556e+004    1.078254448726556e+004
  Column 10
    1.078254448726556e+004
Average error distance is:
ans =
    1.036286774947612e+004
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.500000097914240e+009    9.500000097993382e+009    9.500000097799244e+009
  Columns 4 through 6
    9.500000083235148e+009    9.500000083249212e+009    9.500000097940328e+009
  Columns 7 through 9
    9.500000097958310e+009    9.500000098085400e+009    9.500000097986954e+009
  Column 10
    9.500000097759620e+009
return

exit

 22398 flops.
```

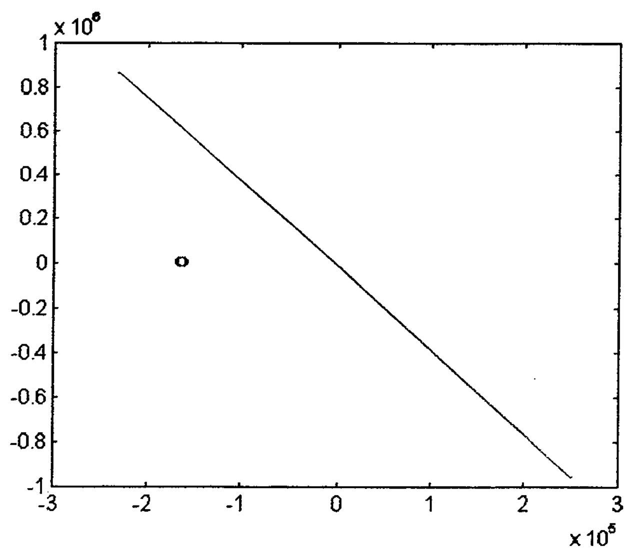


8.6 Test 55 Output

8.6.1 Test 55 Simplex Log

```
nmloc1

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0100    0.0200         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 1000.000  2000.000     0.000
xmtr frequency carrier f0= 9.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000      0.000     10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-     0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    328867.4 m
ellipse angle=  104.961 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2502       940981
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1166       438488


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-140840,534870]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

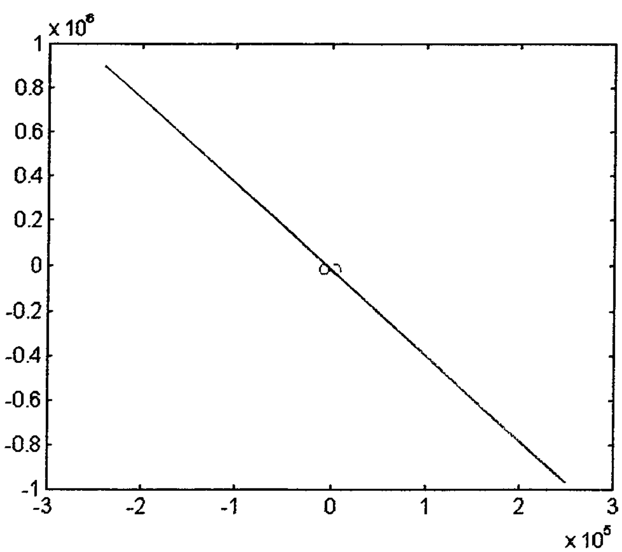
```
Output points are:
xye =
  Columns 1 through 3
   -1.623378159280109e+005   -1.636435862660098e+005   -1.640238747888349e+005
    3.951359709340202e+003    7.592984781708874e+002    1.928915282487980e+003
  Columns 4 through 6
   -1.625083886345056e+005   -1.614012153130074e+005   -1.644522297226463e+005
    2.786997246890486e+002    1.721878549589114e+003    4.046289684839968e+003
  Columns 7 through 9
   -1.630975921711120e+005   -1.639836423311097e+005   -1.633820663904757e+005
    2.540556412860455e+003    1.272418224888672e+003    2.173161068880800e+003
  Column 10
   -1.640788991252906e+005
    1.101931217729898e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.633494717372787e+005    1.646482609650016e+005    1.650238900988524e+005
  Columns 4 through 6
    1.635174486973495e+005    1.624014534623474e+005    1.654648833489136e+005
  Columns 7 through 9
    1.640984824963110e+005    1.649852466497505e+005    1.643821575949122e+005
  Column 10
    1.650813419619418e+005
Average error distance is:
ans =
    1.642952637012658e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.500004897165736e+009    9.500004909984704e+009    9.500004929083926e+009
  Columns 4 through 6
    9.500004874891508e+009    9.500004854545876e+009    9.500004957173784e+009
  Columns 7 through 9
    9.500004907980278e+009    9.500004923341892e+009    9.500004913212462e+009
  Column 10
    9.500004924390406e+009
return

exit

 22398 flops.
```



8.6.2 Test 55 Differential Evolution Log

```
delocl

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0100    0.0200         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 1000.000  2000.000     0.000
xmtr frequency carrier f0= 9.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    328867.4 m
ellipse angle=  104.961 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
       2502      940981
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
       1166      438488


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-140840,534870]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
    6.113264478798956e+003    6.113264478798956e+003    6.113264478798956e+003
   -1.855302800676552e+004   -1.855302800676552e+004   -1.855302800676552e+004
  Columns 4 through 6
    6.113264478798956e+003    6.113264478798956e+003   -6.292246285788715e+003
   -1.855302800676552e+004   -1.855302800676552e+004   -1.770224638103508e+004
  Columns 7 through 9
    6.113264478798956e+003    6.113264478798956e+003    6.113264478798956e+003
   -1.855302800676552e+004   -1.855302800676552e+004   -1.855302800676552e+004
  Column 10
    6.113264478798956e+003
   -1.855302800676552e+004
Output error distances are:
dist =
  Columns 1 through 3
    2.117952865096472e+004    2.117952865096472e+004    2.117952865096472e+004
  Columns 4 through 6
    2.117952865096472e+004    2.117952865096472e+004    2.100845944736570e+004
  Columns 7 through 9
    2.117952865096472e+004    2.117952865096472e+004    2.117952865096472e+004
  Column 10
    2.117952865096472e+004
Average error distance is:
ans =
    2.116242173060482e+004
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    9.500000010301280e+009    9.500000010380422e+009    9.500000010186284e+009
  Columns 4 through 6
    9.500000010382728e+009    9.500000010396794e+009    9.500000334015002e+009
  Columns 7 through 9
    9.500000010345346e+009    9.500000010472436e+009    9.500000010373988e+009
  Column 10
    9.500000010146660e+009

exit

 22398 flops.
```

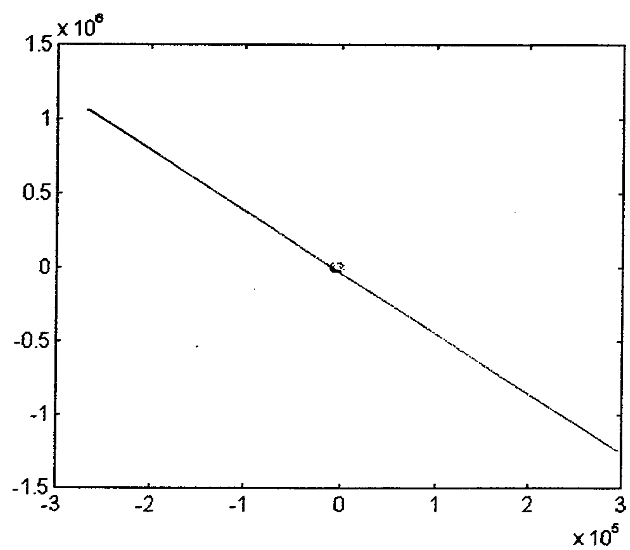


8.7 Test 68 Output

8.7.1 Test 68 Simplex Log

```
nmloc2

sinmod =
  1.0e+005 *
         0          0          0
         0     0.0000          0
    0.0001          0          0
   -0.0300    -0.0150          0
   -0.8282     3.0910     0.0320
         0          0     0.0001
    0.0001          0     0.0030
         0     0.0000     0.0001
         0          0          0
         0          0          0
         0          0          0
         0          0     0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=-3000.000 -1500.000      0.000
xmtr frequency carrier f0= 8.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    393663.8 m
ellipse angle=  104.110 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2984      1126381
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1390       524883


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[20100,-67900]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

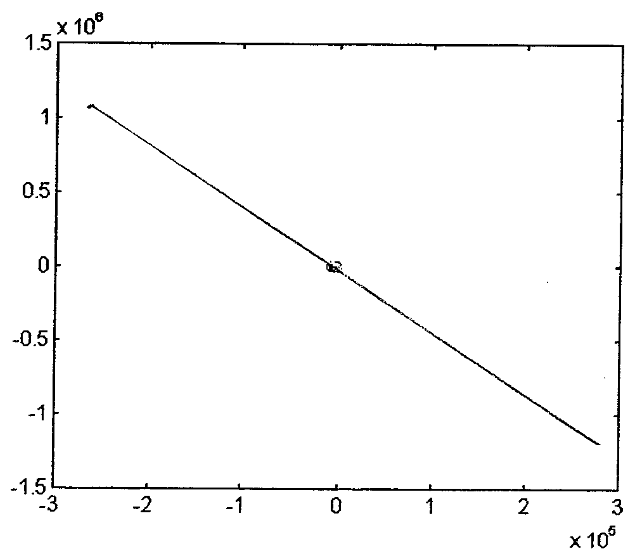
```
Output points are:
xye =
  Columns 1 through 3
   -3.728635497817374e+003    -2.226040786523976e+003    -1.724726188735379e+003
   -5.557634472625384e+002    -4.093882439329543e+003    -2.765440149693458e+003
  Columns 4 through 6
   -3.617502136254756e+003    -4.946113261284298e+003    -1.167972956993666e+003
   -4.639818835891006e+003    -3.079817911336447e+003    -4.209905447427309e+002
  Columns 7 through 9
   -2.829770257128240e+003    -1.834468354755088e+003    -2.493562348399752e+003
   -2.096367137811217e+003    -3.577451469735472e+003    -2.496362665027040e+003
  Column 10
   -1.722493861886378e+003
   -3.780171978790664e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.192682839737832e+003     2.706887321848955e+003     1.796569527225037e+003
  Columns 4 through 6
    3.199964251440184e+003     2.506627506975470e+003     2.126166618786289e+003
  Columns 7 through 9
    6.201870108437682e+002     2.382072338358636e+003     1.117684058765338e+003
  Column 10
    2.613657625967891e+003
Average error distance is:
ans =
    2.026249909994940e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.500000012249920e+009     8.499999997073983e+009     8.499999976109147e+009
  Columns 4 through 6
    8.500000034912791e+009     8.500000058421548e+009     8.499999947428337e+009
  Columns 7 through 9
    8.499999999512821e+009     8.499999984238035e+009     8.499999993689402e+009
  Column 10
    8.499999982417085e+009

exit

 22398 flops.
```



8.7.2 Test 68 Differential Evolution Log

```
deloc2

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
   -0.0300   -0.0150         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=-3000.000 -1500.000     0.000
xmtr frequency carrier f0= 8.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @    0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    393663.8 m
ellipse angle=  104.110 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
       2984     1126381
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
       1390      524883


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5 .3
Number of iterations? default iter=100 12
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[20100,-67900]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -3.232610676810146e+003    -2.749817733466625e+003    -1.794640102982521e+003
   -2.660007119178772e+002    -5.037669652700424e+003    -2.660007119178772e+002
  Columns 4 through 6
   -2.749817733466625e+003    -6.277089878916740e+003    -3.722399868071080e+002
   -5.037669652700424e+003    -2.963068594038486e+003    -1.968423039466143e+003
  Columns 7 through 9
   -2.659924738947302e+003    -1.584034926816821e+003    -1.794640102982521e+003
   -2.713131831586361e+003    -2.295158148184418e+003    -2.660007119178772e+002
  Column 10
   -1.584034926816821e+003
   -2.295158148184418e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.255731647269137e+003     3.546505003256772e+003     1.725006296894354e+003
  Columns 4 through 6
    3.546505003256772e+003     3.588856055257760e+003     2.669183926004015e+003
  Columns 7 through 9
    1.259896830692156e+003     1.623956147529458e+003     1.725006296894354e+003
  Column 10
    1.623956147529458e+003
Average error distance is:
ans =
    2.256460335458424e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.499999997996847e+009     8.500000015888597e+009     8.499999961920931e+009
  Columns 4 through 6
    8.500000015890903e+009     8.500000090987985e+009     8.499999937636835e+009
  Columns 7 through 9
    8.499999999157260e+009     8.499999969922307e+009     8.499999962108629e+009
  Column 10
    8.499999969596534e+009

exit

 22398 flops.
```

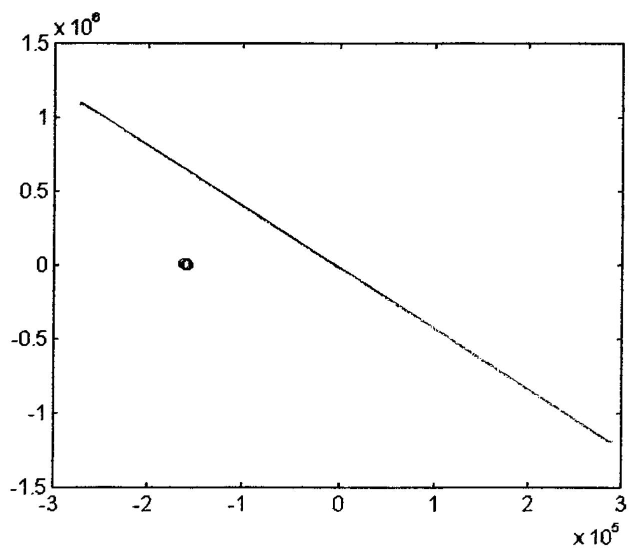


8.8 Test 74 Output

8.8.1 Test 74 Simplex Log

```
nmloc2

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
   -0.0300   -0.0150         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=-3000.000 -1500.000     0.000
xmtr frequency carrier f0= 8.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift), CEP=    393663.8 m
ellipse angle=  104.110 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2984      1126381
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1390       524883


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-254200,1016000]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

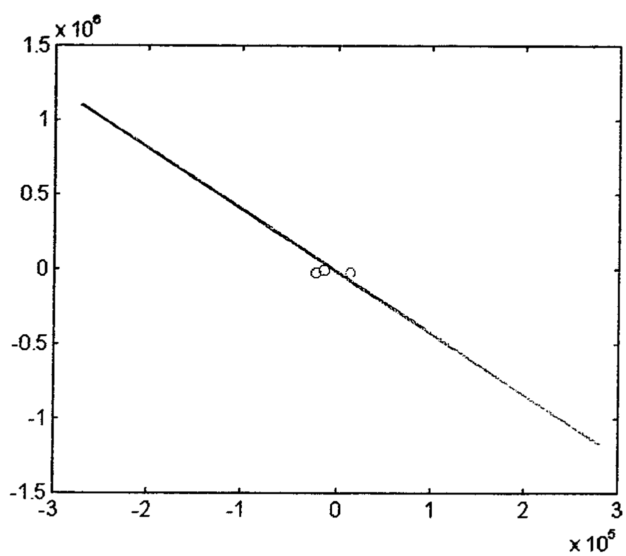
```
Output points are:
xye =
  Columns 1 through 3
   -1.582818736242422e+005    -1.597307353419478e+005    -1.602194444768663e+005
    5.162615018042750e+002    -3.087398663717526e+003    -1.771100285369087e+003
  Columns 4 through 6
   -1.583610497529381e+005    -1.570902143025704e+005    -1.607969220824263e+005
   -3.629073139973982e+003    -2.001307329681433e+003     6.294240801792600e+002
  Columns 7 through 9
   -1.591449119482198e+005    -1.601516931671425e+005    -1.594659612723809e+005
   -1.072573697419945e+003    -2.509119815629524e+003    -1.490487343255500e+003
  Column 10
   -1.602621589035817e+005
   -2.709083125639550e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.552949631723411e+005     1.567387738734270e+005     1.572196782116640e+005
  Columns 4 through 6
    1.553756375136407e+005     1.540910297611476e+005     1.578112894111209e+005
  Columns 7 through 9
    1.561454969589628e+005     1.571549330695731e+005     1.564659615615512e+005
  Column 10
    1.572668067489771e+005
Average error distance is:
ans =
    1.563564570282406e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.500004134910037e+009     8.500004148660775e+009     8.500004168877975e+009
  Columns 4 through 6
    8.500004111274110e+009     8.500004089516870e+009     8.500004198744080e+009
  Columns 7 through 9
    8.500004146630156e+009     8.500004162829322e+009     8.500004152054890e+009
  Column 10
    8.500004163990394e+009
return

exit

 22252 flops.
```



8.8.2 Test 74 Differential Evolution Log

```
deloc2

 sinmod =
   1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
   -0.0300   -0.0150         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=-3000.000 -1500.000     0.000
xmtr frequency carrier f0= 8.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    393663.8 m
ellipse angle=  104.110 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2984     1126381
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1390      524883


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-254200,1016000]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -1.247039332874119e+004   -1.247039332874119e+004   -1.247039332874119e+004
   -1.583231179304421e+004   -1.583231179304421e+004   -1.583231179304421e+004
  Columns 4 through 6
    1.623862123098224e+004   -1.997418484035879e+004   -1.247039332874119e+004
   -3.028619852019474e+004   -3.028619852019474e+004   -1.583231179304421e+004
  Columns 7 through 9
   -1.247039332874119e+004   -1.247039332874119e+004   -1.247039332874119e+004
   -1.583231179304421e+004   -1.583231179304421e+004   -1.583231179304421e+004
  Column 10
   -1.247039332874119e+004
   -1.583231179304421e+004
Output error distances are:
dist =
  Columns 1 through 3
    1.717857709864527e+004    1.717857709864527e+004    1.717857709864527e+004
  Columns 4 through 6
    3.462325478797831e+004    3.341808157627736e+004    1.717857709864527e+004
  Columns 7 through 9
    1.717857709864527e+004    1.717857709864527e+004    1.717857709864527e+004
  Column 10
    1.717857709864527e+004
Average error distance is:
ans =
    2.054699531534178e+004
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.500000316356450e+009    8.500000316435593e+009    8.500000316241453e+009
  Columns 4 through 6
    8.499999729959856e+009    8.500000566502419e+009    8.500000316382533e+009
  Columns 7 through 9
    8.500000316400517e+009    8.500000316527609e+009    8.500000316429156e+009
  Column 10
    8.500000316201829e+009
return

exit

 22398 flops.
```

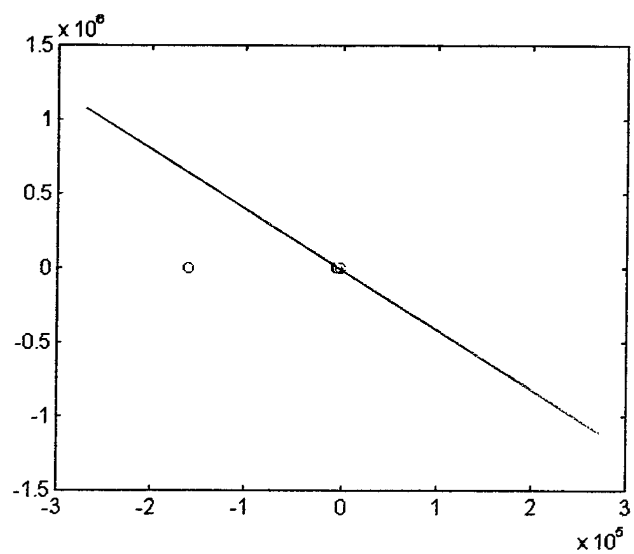


8.9 Test 86 Output

8.9.1 Test 86 Simplex Log

```
nmloc2

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
   -0.0300   -0.0150         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=-3000.000 -1500.000      0.000
xmtr frequency carrier f0= 8.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=      0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000     10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-     0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    393663.8 m
ellipse angle=  104.110 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2984      1126381
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1390       524883

return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[265200,-1058300]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

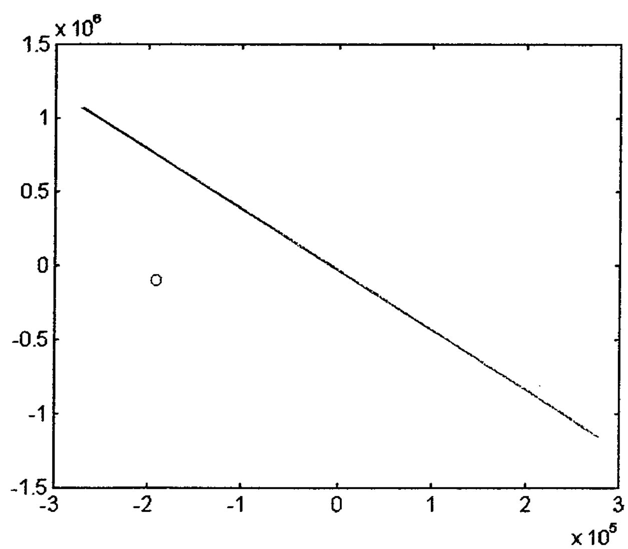
```
Output points are:
xye =
  Columns 1 through 3
   -3.725934146425545e+003   -1.597304614766138e+005   -1.602192622094200e+005
   -5.616023243663249e+002   -3.090154945317933e+003   -1.766660835769476e+003
  Columns 4 through 6
   -3.617288033913987e+003   -4.946188923653464e+003   -1.169019269982240e+003
   -4.641574284366541e+003   -3.089171025150502e+003   -4.248518136201506e+002
  Columns 7 through 9
   -2.830909890384033e+003   -1.601521358465566e+005   -1.594655518843765e+005
   -2.099083294380924e+003   -2.508220796411400e+003   -1.486719295915815e+003
  Column 10
   -1.602584284612038e+005
   -2.709173989424264e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.186410798408910e+003    1.567385279611316e+005    1.572194883520351e+005
  Columns 4 through 6
    3.201645436491452e+003    2.512591465743950e+003    2.123307339122683e+003
  Columns 7 through 9
    6.224887619678287e+002    1.571553699696861e+005    1.564655524480057e+005
  Column 10
    1.572630771154636e+005
Average error distance is:
ans =
    7.944884596480569e+004
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.500000012218891e+009    8.500004148636782e+009    8.500004168901477e+009
  Columns 4 through 6
    8.500000034918263e+009    8.500000058480536e+009    8.499999947479327e+009
  Columns 7 through 9
    8.499999999558269e+009    8.500004162845967e+009    8.500004152068330e+009
  Column 10
    8.500004163897204e+009
return

exit

 22398 flops.
```



8.9.2 Test 86 Differential Evolution Log

```
deloc2

sinmod =
  1.0e+005 *
         0          0          0
         0     0.0000          0
    0.0001          0          0
   -0.0300    -0.0150          0
   -0.8282     3.0910     0.0320
         0          0     0.0001
    0.0001          0     0.0030
         0     0.0000     0.0001
         0          0          0
         0          0          0
         0          0          0
         0          0     0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]=-3000.000 -1500.000     0.000
xmtr frequency carrier f0= 8.500000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000      0.000     10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    393663.8 m
ellipse angle=  104.110 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        2984      1126381
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1390       524883


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .4
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[265200,-1058300]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -1.905467239832878e+005   -1.905467239832878e+005   -1.905467239832878e+005
   -1.053437157751816e+005   -1.053437157751816e+005   -1.053437157751816e+005
  Columns 4 through 6
   -1.905467239832878e+005   -1.905467239832878e+005   -1.905467239832878e+005
   -1.053437157751816e+005   -1.053437157751816e+005   -1.053437157751816e+005
  Columns 7 through 9
   -1.905467239832878e+005   -1.905467239832878e+005   -1.905467239832878e+005
   -1.053437157751816e+005   -1.053437157751816e+005   -1.053437157751816e+005
  Column 10
   -1.905467239832878e+005
   -1.053437157751816e+005
Output error distances are:
dist =
  Columns 1 through 3
    2.143765168642784e+005    2.143765168642784e+005    2.143765168642784e+005
  Columns 4 through 6
    2.143765168642784e+005    2.143765168642784e+005    2.143765168642784e+005
  Columns 7 through 9
    2.143765168642784e+005    2.143765168642784e+005    2.143765168642784e+005
  Column 10
    2.143765168642784e+005
Average error distance is:
ans =
    2.143765168642784e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.500004244221491e+009    8.500004244300632e+009    8.500004244106499e+009
  Columns 4 through 6
    8.500004244302942e+009    8.500004244317006e+009    8.500004244247581e+009
  Columns 7 through 9
    8.500004244265563e+009    8.500004244392651e+009    8.500004244294199e+009
  Column 10
    8.500004244066872e+009
return

exit

 22398 flops.
```

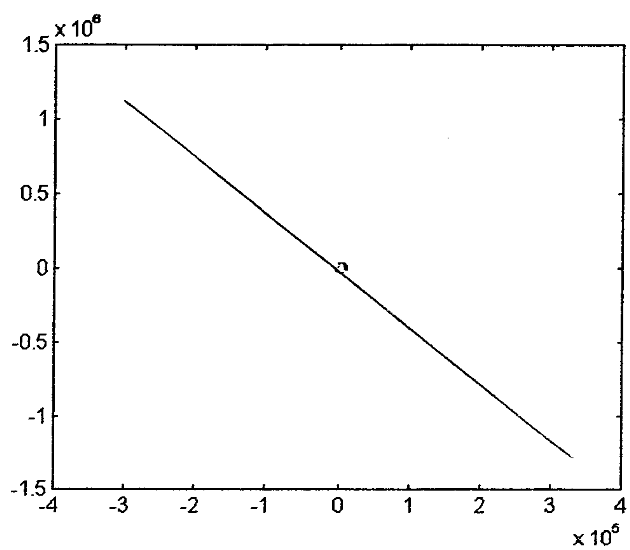


8.10 Test 100 Output

8.10.1 Test 100 Simplex Log

```
nmloc3

sinmod =
  1.0e+005 *
        0          0          0
        0     0.0000          0
   0.0001          0          0
   0.0400    -0.0500          0
  -0.8282     3.0910     0.0320
        0          0     0.0001
   0.0001          0     0.0030
        0     0.0000     0.0001
        0          0          0
        0          0          0
        0          0          0
        0          0     0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 4000.000 -5000.000      0.000
xmtr frequency carrier f0= 8.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000      0.000     10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    405002.0 m
ellipse angle=  105.154 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        3004     1158823
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1400      540001


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[164800,-598700]
nrun =    1
nrun =    2
nrun =    3
nrun =    4
nrun =    5
nrun =    6
nrun =    7
nrun =    8
nrun =    9
nrun =   10
```

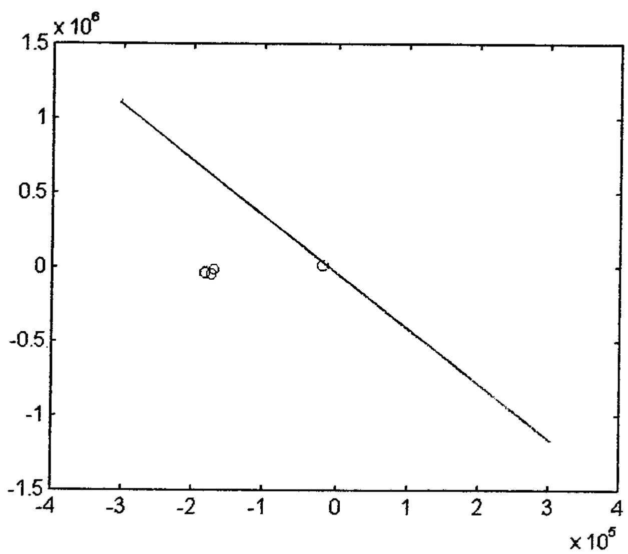
```
Output points are:
xye =
  Columns 1 through 3
    3.226470447892996e+003    4.897731722553174e+003    5.347646296274388e+003
   -3.958377176923671e+003   -7.860606671930746e+003   -6.414646833573681e+003
  Columns 4 through 6
    3.510433127710883e+003    2.097235220929507e+003    5.821051859218442e+003
   -8.446324998851172e+003   -6.705207419920538e+003   -3.843539879975230e+003
  Columns 7 through 9
    4.199351707490283e+003    5.276508046230513e+003    4.558933419788509e+003
   -5.653030588829071e+003   -7.306724502656972e+003   -6.105469284119610e+003
  Column 10
    5.397873584300798e+003
   -7.524701158377331e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.297430565978913e+003    2.998164901597806e+003    1.953810687759210e+003
  Columns 4 through 6
    3.480923975060284e+003    2.555043277407105e+003    2.157227360101538e+003
  Columns 7 through 9
    6.827811166294327e+002    2.636370748443643e+003    1.238736818653745e+003
  Column 10
    2.885856284848190e+003
Average error distance is:
ans =
    2.188634573647986e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.000000011240808e+009    7.999999997302520e+009    7.999999977914929e+009
  Columns 4 through 6
    8.000000032384929e+009    8.000000054086823e+009    7.999999951051719e+009
  Columns 7 through 9
    7.999999999505340e+009    7.999999985372719e+009    7.999999994136193e+009
  Column 10
    7.999999983647496e+009
return

exit

 22252 flops.
```



8.10.2 Test 100 Differential Evolution Log

```
deloc3

sinmod =
  1.0e+005 *
        0         0         0
        0    0.0000         0
   0.0001         0         0
   0.0400   -0.0500         0
  -0.8282    3.0910    0.0320
        0         0    0.0001
   0.0001         0    0.0030
        0    0.0000    0.0001
        0         0         0
        0         0         0
        0         0         0
        0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 4000.000 -5000.000     0.000
xmtr frequency carrier f0= 8.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000      0.000    10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=    4.8500sec and
varies over  3200.0m +/-     0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    405002.0 m
ellipse angle=  105.154 d ccw from x,  mean freq.dev=     1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
       3004      1158823
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
       1400       540001


return

Population size? default np=10 11
Scaling factor f? (0<f<=1.2) default f=.9 .6
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 12
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[164800,-598700]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
   -1.714100377754080e+004   -1.724122668192733e+005   -1.724122668192733e+005
    1.765764843579149e+003   -4.873650376769665e+004   -4.873650376769665e+004
  Columns 4 through 6
   -1.724122668192733e+005   -1.681420771277872e+005   -1.813104037330862e+005
   -4.873650376769665e+004   -2.634302875212690e+004   -3.804187686950260e+004
  Columns 7 through 9
   -1.714100377754080e+004   -1.724122668192733e+005   -1.724122668192733e+005
    1.765764843579149e+003   -4.873650376769665e+004   -4.873650376769665e+004
  Column 10
   -1.724122668192733e+005
   -4.873650376769665e+004
Output error distances are:
dist =
  Columns 1 through 3
    2.219724340184172e+004    1.817530457685269e+005    1.817530457685269e+005
  Columns 4 through 6
    1.817530457685269e+005    1.734601383436066e+005    1.882331303431433e+005
  Columns 7 through 9
    2.219724340184172e+004    1.817530457685269e+005    1.817530457685269e+005
  Column 10
    1.817530457685269e+005
Average error distance is:
ans =
    1.496606030101594e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.000000461813936e+009    8.000004070499627e+009    8.000004070305490e+009
  Columns 4 through 6
    8.000004070501933e+009    8.000004101492758e+009    8.000004311080011e+009
  Columns 7 through 9
    8.000000461858004e+009    8.000004070591644e+009    8.000004070493195e+009
  Column 10
    8.000004070265866e+009
return

exit

 22252 flops.
```

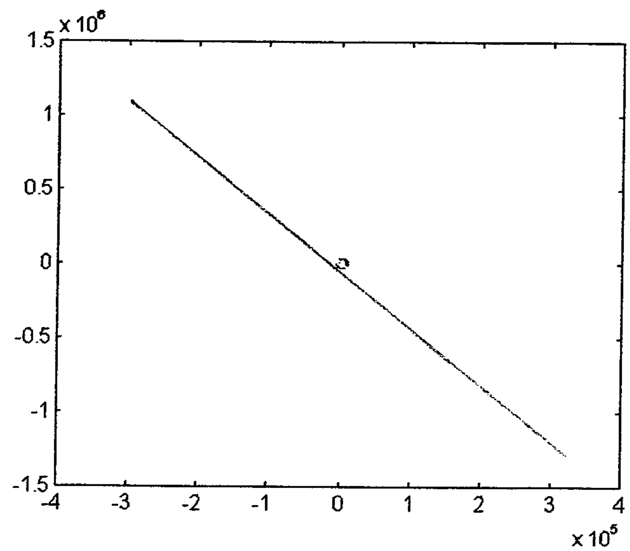


8.11 Test 102 Output

8.11.1 Test 102 Simplex Log

```
nmloc3

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0400   -0.0500         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 4000.000 -5000.000     0.000
xmtr frequency carrier f0= 8.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=     0.000     0.000    10.000
sine wave period=    9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    405002.0 m
ellipse angle=  105.154 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        3004      1158823
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1400       540001


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-69200,250800]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

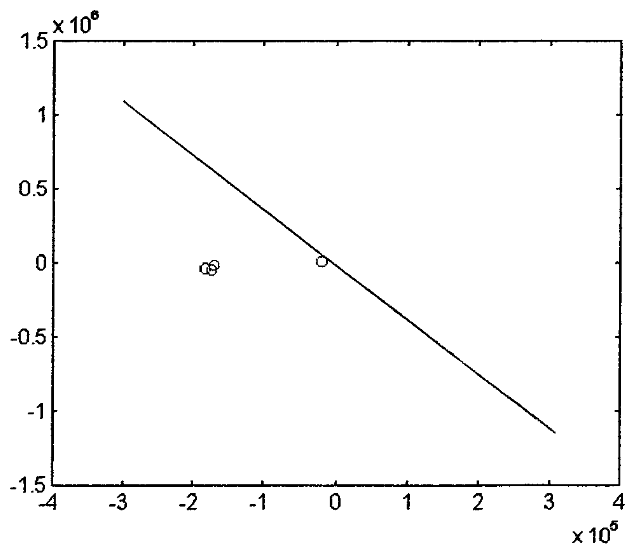
```
Output points are:
xye =
  Columns 1 through 3
   -1.651895579122288e+005   -1.668165159137960e+005   -1.672584272426115e+005
   -2.779529512681209e+003   -6.756121137200142e+003   -5.308904139231770e+003
  Columns 4 through 6
   -1.654494201100456e+005   -1.640863877377132e+005   -1.677415818014870e+005
   -7.327597667883598e+003   -5.509722173182094e+003   -2.684480261198104e+003
  Columns 7 through 9
   -1.661318260910035e+005   -1.672167364298992e+005   -1.664791533432485e+005
   -4.528527996083697e+003   -6.121308799183712e+003   -4.994006559045327e+003
  Column 10
   -1.673393179877690e+005
   -6.343773811343987e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.692041281875844e+005    1.708255427925714e+005    1.712587058323754e+005
  Columns 4 through 6
    1.694654055745132e+005    1.680871606024883e+005    1.717571906830617e+005
  Columns 7 through 9
    1.701324793650816e+005    1.712204081502222e+005    1.704791534486026e+005
  Column 10
    1.713445873570854e+005
Average error distance is:
ans =
    1.703774761993586e+005
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.000004174312487e+009    8.000004187100427e+009    8.000004205956766e+009
  Columns 4 through 6
    8.000004152449573e+009    8.000004132256655e+009    8.000004233693302e+009
  Columns 7 through 9
    8.000004185189260e+009    8.000004200235727e+009    8.000004190289021e+009
  Column 10
    8.000004201320857e+009
return

exit

 22252 flops.
```



8.11.2 Test 102 Differential Evolution Log

```
deloc3

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0400   -0.0500         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 4000.000 -5000.000     0.000
xmtr frequency carrier f0= 8.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    405002.0 m
ellipse angle=  105.154 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        3004      1158823
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1400      540001


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5 .3
Number of iterations? default iter=100 10
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[-69200,250800]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
    7.807963418960571e+003     7.807963418960571e+003     7.807963418960571e+003
   -5.337110739946365e+003    -5.337110739946365e+003    -5.337110739946365e+003
  Columns 4 through 6
    7.807963418960571e+003     7.807963418960571e+003     7.807963418960571e+003
   -5.337110739946365e+003    -5.337110739946365e+003    -5.337110739946365e+003
  Columns 7 through 9
    7.807963418960571e+003     7.807963418960571e+003     7.807963418960571e+003
   -5.337110739946365e+003    -5.337110739946365e+003    -5.337110739946365e+003
  Column 10
    7.807963418960571e+003
   -5.337110739946365e+003
Output error distances are:
dist =
  Columns 1 through 3
    3.822856137906457e+003     3.822856137906457e+003     3.822856137906457e+003
  Columns 4 through 6
    3.822856137906457e+003     3.822856137906457e+003     3.822856137906457e+003
  Columns 7 through 9
    3.822856137906457e+003     3.822856137906457e+003     3.822856137906457e+003
  Column 10
    3.822856137906457e+003
Average error distance is:
ans =
    3.822856137906457e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    7.999999915350590e+009     7.999999915429733e+009     7.999999915235593e+009
  Columns 4 through 6
    7.999999915432038e+009     7.999999915446100e+009     7.999999915376675e+009
  Columns 7 through 9
    7.999999915394660e+009     7.999999915521744e+009     7.999999915423299e+009
  Column 10
    7.999999915195971e+009
return

exit

 22398 flops.
```

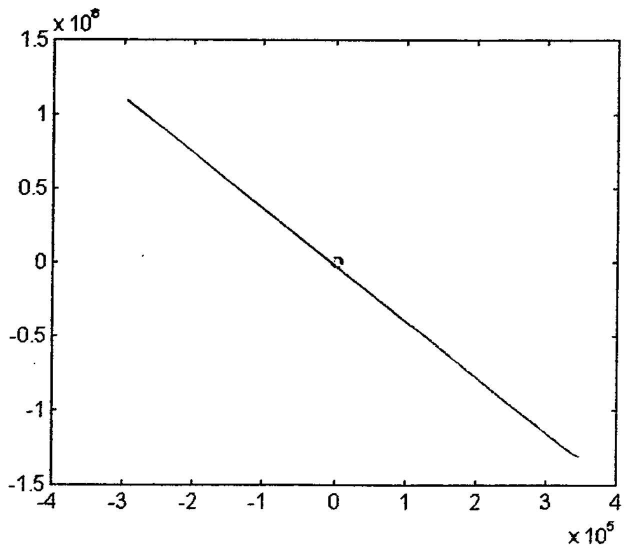


8.12 Test 120 Output

8.12.1 Test 120 Simplex Log

```
nmloc3

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0400   -0.0500         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 4000.000 -5000.000     0.000
xmtr frequency carrier f0= 8.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000      0.000     10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-     0.0m
samples @    0.200 sec from t=    0.000 to t=   10.000
total samples =     51
X,Y proj. CRB ellipse (freq. only+linear drift),  CEP=    405002.0 m
ellipse angle=  105.154 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        3004     1158823
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1400      540001


return

how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[292700,-1083600]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

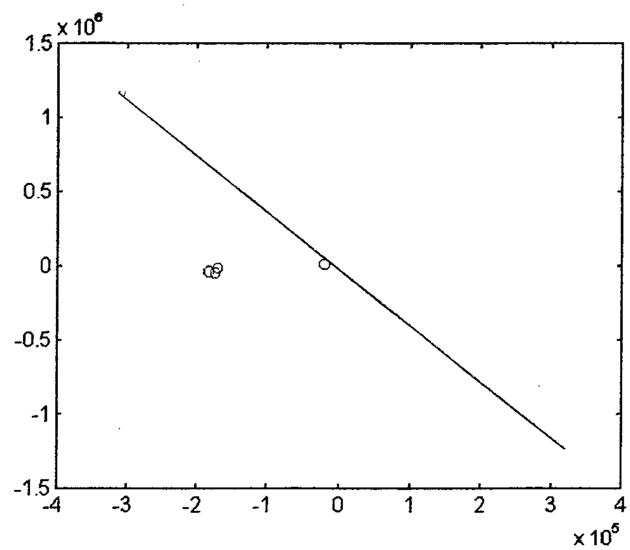
```
Output points are:
xye =
  Columns 1 through 3
    3.224859611628761e+003    4.900516103774446e+003    5.348627405636684e+003
   -3.954573720481056e+003   -7.860802600632675e+003   -6.410964413326306e+003
  Columns 4 through 6
    3.510158973872018e+003    2.096839207328099e+003    5.817603655274868e+003
   -8.446549397352606e+003   -6.705941848100218e+003   -3.846620665464828e+003
  Columns 7 through 9
    4.199955087403476e+003    5.274262355664172e+003    4.558195845109231e+003
   -5.651291719235579e+003   -7.299228914963067e+003   -6.101784636388991e+003
  Column 10
    5.397659796943928e+003
   -7.527134445863147e+003
Output error distances are:
dist =
  Columns 1 through 3
    1.301444861526271e+003    2.999186685243814e+003    1.951823879069928e+003
  Columns 4 through 6
    3.481184709157176e+003    2.555828357277367e+003    2.152665077758581e+003
  Columns 7 through 9
    6.812950466012271e+002    2.628725576104331e+003    1.235116183393299e+003
  Column 10
    2.887881821588511e+003
Average error distance is:
ans =
    2.187515219772050e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.000000011254238e+009    7.999999997240570e+009    7.999999977869617e+009
  Columns 4 through 6
    8.000000032392523e+009    8.000000054100334e+009    7.999999951150151e+009
  Columns 7 through 9
    7.999999999480761e+009    7.999999985377131e+009    7.999999994130120e+009
  Column 10
    7.999999983667452e+009
return

exit

 22398 flops.
```



8.12.2 Test 120 Differential Evolution Log

```
deloc3

sinmod =
  1.0e+005 *
         0         0         0
         0    0.0000         0
    0.0001         0         0
    0.0400   -0.0500         0
   -0.8282    3.0910    0.0320
         0         0    0.0001
    0.0001         0    0.0030
         0    0.0000    0.0001
         0         0         0
         0         0         0
         0         0         0
         0         0    0.0000
position,velocity, acc. accuracies (1 sigma -m,sec units)
[sigp, sigv, siga]= 0.000  0.000  0.000
attitude,freq, phase accuracies (1 sigma -deg,Hz units)
[sigatt,sigf,sigphi]= 0.000  1.000  0.000
xmtr location [xt,yt,ht]= 4000.000 -5000.000     0.000
xmtr frequency carrier f0= 8.000000000 Ghz
xmtr frequency drift fd=    0.000 Hz/sec
t=t0 rcvr location [xr,yr,hr]=-82820.000 309100.000  3200.000
OPTION 1: A/C moves on a sine wave along tilted axis
sine wave tilt (d.ccw from x-axis)=     0.000
velocity along sine axis=  300.000 m/sec
vmax, max Gs, sine amp.=    0.000     0.000    10.000
sine wave period=   9.7000 sec
rcvr altitude is sinusoidal with period=   4.8500sec and
varies over  3200.0m +/-    0.0m
samples @   0.200 sec from t=    0.000 to t=   10.000
total samples =      51
X,Y proj. CRB ellipse (freq. only+linear drift), CEP=    405002.0 m
ellipse angle=  105.154 d ccw from x,  mean freq.dev=    1.000 Hz
Pinc=0.9000 SEMI-AXIS LENGTHS (meters)
        3004      1158823
Pinc=0.3935 SEMI-AXIS LENGTHS (meters)
        1400       540001


return

Population size? default np=10
Scaling factor f? (0<f<=1.2) default f=.9 .5
Crossover constant cr? (0<=cr<=1) default cr=.5
Number of iterations? default iter=100 15
how many Monte Carlo runs? (0 to stop) nmc=10
initial estimates in format: [xt,yt]?[292700,-1083600]
nrun =     1
nrun =     2
nrun =     3
nrun =     4
nrun =     5
nrun =     6
nrun =     7
nrun =     8
nrun =     9
nrun =    10
```

```
Output points are:
xye =
  Columns 1 through 3
    2.485299777216278e+003    6.594068590737879e+003    4.539684183977079e+003
   -6.065349885294563e+003   -1.606812305604399e+004   -6.065349885294563e+003
  Columns 4 through 6
   -6.650370299816132e+002    6.594068590737879e+003    5.842990333575290e+003
   -6.130249750331859e+003   -1.606812305604399e+004   -2.629558266112362e+004
  Columns 7 through 9
    4.539684183977079e+003    6.594068590737879e+003    4.539684183977079e+003
   -6.065349885294563e+003   -1.606812305604399e+004   -6.065349885294563e+003
  Column 10
    6.594068590737879e+003
   -1.606812305604399e+004
Output error distances are:
dist =
  Columns 1 through 3
    1.851833454444053e+003    1.136804907788426e+004    1.194248465157960e+003
  Columns 4 through 6
    4.800003644709544e+003    1.136804907788426e+004    2.137518313948213e+004
  Columns 7 through 9
    1.194248465157960e+003    1.136804907788426e+004    1.194248465157960e+003
  Column 10
    1.136804907788426e+004
Average error distance is:
ans =
    7.708196194564666e+003
Output ML freqs are:
f0ecs =
  Columns 1 through 3
    8.000000041217291e+009    8.000000009159531e+009    7.999999994138213e+009
  Columns 4 through 6
    8.000000114142132e+009    8.000000009175896e+009    8.000000084861946e+009
  Columns 7 through 9
    7.999999994297275e+009    8.000000009251547e+009    7.999999994325913e+009
  Column 10
    8.000000008925767e+009

exit

 22398 flops.
```



8.13 CODE LISTINGS

8.13.1 MATLAB Files

These files are the source for the MATLAB portion of the simulator:

nmloc.m, nmloc1.m, nmloc2.m, nmloc3.m, deloc.m, deloc1.m, deloc2.m, deloc3.m, data.m, data1.m, data2.m, and data3.m.

(To conserve printing costs, only the headers are reproduced in this document. Please contact Mercer Engineering Research Center for magnetic copies of the actual MATLAB code.)

8.13.1.1 File nmloc.m

```
% NMLOC.M  this program uses the Nelder-Mead Simplex method to locate
% a transmitter using measurements from a moving platform.
%
% 28 September 1998
% 1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%       64-bit floating-point emulation.
%
```

8.13.1.2 File nmloc1.m

```
% NMLOC.M  this program uses the Nelder-Mead Simplex method to locate
% a transmitter using measurements from a moving platform. It uses data
% file DATA1.M
% 3 October 1998
% 1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%       64-bit floating-point emulation.
%
```

8.13.1.3 File nmloc2.m

```
% NMLOC2.M  this program uses the Nelder-Mead Simplex method to locate
% a transmitter using measurements from a moving platform. It uses data
% file DATA2.M
% 5 October 1998
% 1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%       64-bit floating-point emulation.
%
```

8.13.1.4 File nmloc3.m

```
% NMLOC3.M  this program uses the Nelder-Mead Simplex method to locate
% a transmitter using measurements from a moving platform. It uses data
% file DATA3.M
% 7 October 1998
% 1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%       64-bit floating-point emulation.
%
```

8.13.1.5 File deloc.m

```
% DELOC.M  this program uses the Differential Evolution method to locate
% a transmitter using measurements from a moving platform.
%
% 29 September 1998 - Version 1.2
% 1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%       64-bit floating-point emulation.
%
```

```
%  1.2 - Calls dec95.dll
%
```

8.13.1.6 File deloc1.m

```
%  DELOC1.M  this program uses the Differential Evolution method to locate
%  a transmitter using measurements from a moving platform.  It uses data
%  file DATA1.M
%  3 October 1998 - Version 1.2
%  1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%        64-bit floating-point emulation.
%
%  1.2 - Calls dec95.dll
%
```

8.13.1.7 File deloc2.m

```
%  DELOC2.M  this program uses the Differential Evolution method to locate
%  a transmitter using measurements from a moving platform.  It uses data
%  file DATA2.M
%  5 October 1998 - Version 1.2
%  1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%        64-bit floating-point emulation.
%
%  1.2 - Calls dec95.dll
%
```

8.13.1.8 File deloc3.m

```
%  DELOC3.M  this program uses the Differential Evolution method to locate
%  a transmitter using measurements from a moving platform.  It uses data
%  file DATA3.M
%  7 October 1998 - Version 1.2
%  1.1 - Added call to floatf.exe to load WIN87EM.DLL and turn on
%        64-bit floating-point emulation.
%
%  1.2 - Calls dec95.dll
%
```

8.13.1.9 File data.m

```
% DATA.M array
%
```

8.13.1.10 File data1.m

```
% DATA1.M array
%
```

8.13.1.11 File data2.m

```
% DATA2.M array
%
```

8.13.1.12 File data3.m

```
% DATA3.M array
%
0.0            0.0      1    ]    %12 fdrft(Hz)    ZsineAmp(m)      OPT#
```

8.13.2 C++ Files

These files are the source for the C++ portion of the simulator:
nmc275.cpp, dec95.cpp, floatf.cpp.

These files are required in order to compile the C++ dlls:
stdlib2.h, mex.h, dllmex.h, dllmatrx.h.

Note that stdlib2.h is stdlib.h modified to work with the MATLAB cmex.bat compiler switches. The two files dllmex.h and dllmatrx.h are distributed with MATLAB, but are altered slightly here to allow them to compile under C++.

8.13.2.1 File nmc275.cpp

```
#include <math.h>
#include <stdio.h>
#include "mex.h"
#include "stdlib2.h"
#include <iostream.h>
#define NR_END 1
#define FREE_ARG char*
#define TINY 1.0e-10 A small number.
#define NMAX 5000
//Maximum allowed number of function evaluations.
#define GET_PSUM \
for (j=0;j<ndim;j++) {\
for (sum=0.0,i=0;i<mpts;i++) sum += points[i][j];\
psum[j]=sum;}
#define SWAP(a,b) {swap=(a);(a)=(b);(b)=swap;}
//*******************************************************
//                Nelder-Mead Simplex                   *
//                  Minimizer in C++                    *
//                  Version 1.0                         *
//                                                      *
//           nmc272.cpp - main and other Functions      *
//                                                      *
//                                                      *
//*******************************************************
//***************************************************************
//funk is the function to minimize - adapted from dopfit.m
//***************************************************************
```

8.13.2.2 File dec95.cpp

```
#include <math.h>
#include "mex.h"
#include "stdlib2.h"
/*------Constants for rnd_uni()--------------------------------------------*/
#define IM1 2147483563
#define IM2 2147483399
#define AM (1.0/IM1)
#define IMM1 (IM1-1)
#define IA1 40014
#define IA2 40692
#define IQ1 53668
#define IQ2 52774
#define IR1 12211
#define IR2 3791
#define NTAB 32
#define NDIV (1+IMM1/NTAB)
#define EPS 1.2e-7
#define RNMX (1.0-EPS)
//*******************************************************
//                Differential Evolution               *
//                   Minimizer in C++                   *
//                  Version 1.0                         *
//                                                      *
//          dec95.cpp - main and other Functions        *
//                                                      *
//                                                      *
//*******************************************************
```

8.13.2.3 File floatf.cpp

```
  void main ( )
  {
double x = 1000000.0;
double y = 500000.0;
x = x/y;
}
```

8.13.2.4 File stdlib2.h

```
/*  stdlib.h
    Definitions for common types, variables, and functions.
*/
/*
 *      C/C++ Run Time Library - Version 6.5
 *
 *      Copyright (c) 1987, 1994 by Borland International
 *      All Rights Reserved.
 *
 */
```

8.13.2.5 File mex.h

```
#ifdef DLLMEX
#include "dllmex.h"
#else
#include "mx3mex.h"
#endif
```

8.13.2.6 File dllmex.h

```
/*
 * @(#)dllmex.h    generated by: makeheader    Fri Mar 18 15:53:49 1994
 *
 *             built from:    cmexmain.c
 *
 *    Modified to handle C++ files by adding "C" after the externs as
 *    per directions on page 29 of the BC++ Programmer's Guide
 */
```

8.13.2.7 File dllmatrx.h

```
/*
 * @(#)dllmatrx.h    generated by: makeheader    Fri Mar 18 15:53:50 1994
 *
 *             built from:    matdll.c
 *                            cmexmain.c
 *    Modified by adding "C" to extern to make it work with C++
 *    as per directions in BC++ Programmer's Guide.
 */
```

9 REFERENCES

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Chong, Edwin K.P., and Zak, Stanislaw H. (1986). "Genetic Algorithms." An Introduction to Optimization (Chapter 14). Wiley.

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Press, William H., Teukolsky, Saul A., Vetterling, William T., & Flannery, Brian P. (1992). "Minimization or Maximization of Functions." Numerical Recipes in C (pp. 408-412). New York, NY: Cambridge University Press.

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10 LIST OF ACRONYMS

AED - Average Error Distance

DE - Differential Evolution

DLL – Dynamically Linked Library

MERC - Mercer Engineering Research Center

ML - Maximum Likelihood

SSE - Sum Squared Error

6. Conclusions And Plans For Future Activity

RAPCEval program participants have agreed on the success of this program and the quality of the results that have been produced to date. A very satisfying feature of the work has been the stimulation of cooperation among various engineering communities and their fruitful interaction. Students, university faculty, government and private sector engineers have united in the common attack on a number of priority Air Force electronic warfare concerns. The students' master's degree research has focused on topics that have immediate impact on the transitioning of new and improved software and hardware technologies into fielded systems.

Thirteen master's degrees have been awarded at the time of this report. The title of each report is listed in the table together with availability information for each document.

#	*Author*	*Report Title*	*Security Designation*	*Availability*
1	Mark Astin	"Parallelization of the RAD Filter"	Classified	Obtain from AFRL/SNRP – Document AFRL-SN-WP-TR-1998-1088
2	Henderson Benjamin	"Neural Network System That Selects Reed-Solomon Codes for a Specific Application	Unclassified	Obtain from AFRL/SNRP: Document AFRL-SN-TR-1999-1115, Section 5.4
3	Ron Brinkley	Burst Error Correction with Reed-Solomon Codes	Unclassified	Obtain from AFRL/SNRP: #AFRL-SN-TR-1999-1115, Section 5.4
4	Mark Campbell	"Auto-Regressive Spectral Analysis - EW Applications"	Unclassified	Obtain from MERC or AFRL/SNRP: #WL-TR-94-1057, Appendix E
5	Randy Ford	"Comparison of Differential Evolution to the Simplex Method in Optimization during Passive Emitter Location"	Unclassified	Published in *this* document (see Section 5.5)
6	Claus Franzkowiak	"Four-Pulse RAD Filter Extension"	Classified	Obtain from AFRL/SNRP – Document AFRL-SN-WP-TR-1998-1087
7	Neal Garner	"Error Correction and Prediction for Improved Communication of Time and Time Measurements"	Unclassified	Obtain from AFRL/SNRP: Document WL-TR-96-1161, Appendix D

8	Joseph Kelley	"A Parameter Determination Alternative for RAD Analysis"	Classified	Obtain from AFRL/SNRP, WPAFB, Document WL-TR-95-1005
9	Joseph Kelley	"MultiGroup Simultaneous RAD Parameter Selection"	Classified	Obtain from AFRL/SNRP, WPAFB, Document WL-TR-97-1094
10	Max Roesel	"Agile RF/PRI Radar Analysis via RAD"	Classified	Obtain from AFRL/SNRP, WPAFB, Document WL-TR-95-1020
11	Dave Schuler	"Comparison of Algorithms for Geolocation of Radar Signals"	Unclassified	call MERC for access - requires establishment of "need-to-know" status
12	Tracy Tillman	"Hardware Implementation for Advance Pulse Processing Algorithm	Classified	Obtain from AFRL/SNRP, WPAFB, Document AFRL-SN-WP-TR-2000-1007
13	Kirk Wright	"Object Oriented Modeling of the AN/ALQ-172"	Classified	Obtain from AFRL/SNRP - Document AFRL-SN-WP-TR-1998-1086

7. LIST OF ABBREVIATIONS AND ACRONYMS

AAA – Anti-Aircraft Artillery

AAM - Anti-Aircraft Missile

A/D – Analog to Digital

ADS – Advanced Digital System (Radar Receiving Product of Litton, San Jose)

AFRL – Air Force Research Laboratory

AFRL/SNR – Air Force Research Laboratory/Sensors Division

AN/AAR-47 – Air Force Infrared Missile Warning System

BOA – Basic Order Agreement

DTIC – Defense Technical Information Center

ELINT – Electronic Intelligence

EO – Electro-Optical

EW – Electronic Warfare

FPGA – Field Programmable Gate Array

GNEC – Trade Name for Version of NEC

GPS – Global Positioning Satellite

IFF – Interrogate Friend or Foe

IR – Infra-red

MERC - Mercer Engineering Research Center

NEC – Numerical Electromagnetic Code

PLAID – Precision Location and Identification

PRSComm – Program Research Standards Committee

RAPCEval 2 –Receiver and Processing Concepts Evaluation Progam

RCS – Radar Cross Section

RF – Radio Frequency

SAM – Surface-to-Air Missile

SIGINT – Signal Intelligence

UV – Ultraviolet

V2 – Version 2 Update

WR-ALC - Warner Robins Air Logistics Center